

A LIMNOLOGICAL STUDY
OF THE PROFUNDAL BOTTOM FAUNA
OF CERTAIN FRESH-
WATER LAKES

A DISSERTATION SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY IN
THE UNIVERSITY OF MICHIGAN

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Reprinted from
ECOLOGICAL MONOGRAPHS
Vol. 1, No. 3, 1931



ECOLOGICAL MONOGRAPHS

Vol. I

JULY, 1931

No. 3

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A LIMNOLOGICAL STUDY OF THE PROFUNDAL BOTTOM FAUNA OF CERTAIN FRESH-WATER LAKES*

INTRODUCTION

In fresh-water lakes few animals have proved themselves capable of living in that unusual habitat, the anaerobic profundal zone of the lake bottom. Although this qualitatively limited fauna is ordinarily exposed to continuously low temperatures, little or no light, a pH often falling below neutrality, relatively large amounts of free carbon dioxide, a total lack of dissolved oxygen for months at a time and in some instances the accumulation of certain decomposition gases, it nevertheless comprises a population of bottom-dwelling animals frequently amounting to many thousand individuals per square meter.

It is the purpose of this paper to present the results from a study of the macroscopic profundal bottom fauna in which the principal emphasis has been placed on the ecological relations of the animals involved rather than on the qualitative and quantitative aspects alone, as has been so frequently done in the past. Aquatic productivity is certainly to be measured in terms of quality and quantity. However, to stop there is to leave a large and fundamentally important part in the complete problem of biological productivity wholly untouched. The aim throughout this investigation has been to discover not only the nature, quantity and distribution of the bottom fauna beneath the deeper waters, but having done that, to study and measure the environmental influences in an attempt to evaluate their limnological importance. During the work, the writer has become convinced of the need for great caution in pointing out any single factor as the sole determining influence in the abundance and distribution of bottom animals.

Field work was begun in February, 1923, and discontinued in the third week of August for that year. During the summer of 1925, field studies occupied about three weeks, while in June, 1926, the work was again taken up and has been in continuous progress, with only minor interruptions, since that time. The last field records included are for February 9, 1929.

The major portion of this investigation was conducted on two Michigan lakes, Douglas and Third Sister. Several other Michigan and New York lakes were studied and data from one of these (Kirkville Green Lake in New York) are included in this paper.

The total number of bottom samples, 1879, were obtained as follows: 1331 from Douglas Lake, of which 1007 came from the profundal zone

* Contribution from the University of Michigan Biological Station and from the Zoölogical Laboratory, University of Michigan.

within the six major depressions and the remaining 324 from numerous sampling series extending from the deepest water as far up the slope as any significant numbers of profundal animals were found; 403 from Third Sister, 163 of these being from below the 18 m. contour; and 145 from the deeper water of Kirkville Green Lake.

In addition to these qualitative and quantitative bottom samples, more than 180 vertical series of physical-chemical determinations have been made; a considerable amount of experimental work conducted in the lakes studied and in the laboratory; some further physical analyses made; certain original hydrographic and morphometric work done and a large amount of general ecological data relating to the problem collected. Obviously, not all this mass of data in its original detail can be included here, and, in fact, that which is presented is very largely in summarized form. Details are given only where necessary for clarity.

METHODS AND EQUIPMENT

Physical

Morphometric data have been derived from various sources. Some were from original work and, in such instances, surveying compasses, surveyor's transits, and steel tapes constituted the equipment. In studying the maps, areas were determined by a polar planimeter; shore and contour lengths by a standard map measurer.

Certain determinations of relative transparency were made, using a Secchi's disc under standard conditions. Temperatures were determined with Negretti-Zambra reversing thermometers.

For physical examination and analysis of bottom deposits, samples were collected with an Ekman-Birge dredge (Ekman, 1911; Birge, 1922). After collection, the samples were put through a set of 6 Tyler Standard Scale Screens with mesh openings of 4.7, 2.4, 1.2, 0.4, 0.2, and 0.15 mm., respectively, to determine the composition and fineness of the mud. For determining amounts of water and of volatile and non-volatile solids present in bottom mud, use was made of heavy analytical balances for weighing the wet mud; electric oven for drying; fused silica crucibles and gas blast lamp for ignition; and, finally, Chainomatic analytical balances for determining loss on ignition.

Chemical

Hydrogen ion concentration was determined colorimetrically in the field at the time of sampling. Sets of color standard tubes prepared by the manufacturer and standard indicators were purchased from La Motte Chemical Products Co. A new series was secured annually. Regular and frequent checking of such sets both electrometrically and against duplicate tubes was a regular procedure.

Dissolved oxygen was determined by the Rideal-Stewart modification of the Winkler method as given by Standard Methods of Water Analysis. Samples collected in the field were at once treated with the reagents up to the final titration point and stored in covered cases until the laboratory had been reached. Final titrations were always made within 6 hours, usually much less, from the time of collection. Frequent standardization of reagents was routine practice.

For free carbon dioxide determinations, N/44 KOH and phenolphthalein were employed. These analyses were always made as quickly as possible after the sample had been brought into the boat. Phenolphthalein alkalinity and methyl orange alkalinity titrations have also been part of the regular work. In each of these determinations the procedure described in the previously mentioned Standard Methods was followed.

Water for all chemical analyses was collected with the modified Kemmerer Water Bottle (Birge, 1922, pp. 547-549, Pl. XL, Figs. 6-7). Portable chemical, instrument and sample bottle kits, designed by Professor Paul S. Welch have made possible accurate physical-chemical determinations in the field, with the exception of final titrations as noted.

Biological

All bottom samples were taken with a small Ekman-Birge dredge which collected a sample of 225 sq. cm. surface area. In the soft mud bottom of most lakes studied, the dredge always came up filled to the top. Usually, however, the upper layer was composed of "dust-fine detritus" in suspension and the lower part of more solid mud. On firmer but still definitely muddy bottoms, the dredge penetrated to a depth of 5-10 cm. With the increase of sand or fine gravel in the mud the dredge worked less and less satisfactorily, until it failed in about 75 per cent of the trials on sandy bottoms.

Usually at least 5 hauls were made with the dredge and placed together as a sample from a particular depth or station. Frequently, 10 or 15 and sometimes as many as 50 hauls were thus combined into one sample. Care was exercised, however, to see that they were truly random samples within the area studied.

The mud was emptied from the dredge into a pail, stirred with the hand to reduce it to a uniform consistency, and then transferred to a deep pan, 50 cm. in diameter, which had a bottom composed of brass screening with a mesh fine enough to retain the smallest macroscopic organisms.

The captured animals, together with the coarse debris, left in the screen after the mud had been removed by a thorough washing in the lake, were at once transferred to wide-mouthed bottles and enough water added to keep them alive until the laboratory had been reached. There they were sorted and counted. Much of the material was either preserved in vials or used for experiments. Some insect larvae and pupae were isolated and reared. Many

were placed in rearing cages, each of which usually contained representatives of but one genus. Such cages were constructed of two parts, the lower halves being glass-sided, slate-bottomed, rectangular aquaria provided with a layer of mud and a supply of running lake water while the upper halves were constructed of a wire framework shaped like the aquaria and inverted over them but covered with fine mesh cotton screening.

For determining the number of *Corethra* larvae at different levels in the lake, a closing plankton net (Juday, 1916, pp. 573-575, Pl. XXXIV, Figs. 1-3) equipped with No. 6, standard quality bolting cloth, was used. This size of mesh (28 per cm.) caught even the youngest larvae, when present, and yet by reason of its lower resistance to the water it increased the efficiency considerably over a net with No. 20 bolting cloth.

Regular procedure when making physical-chemical determinations and qualitative-quantitative bottom fauna collections was as follows:

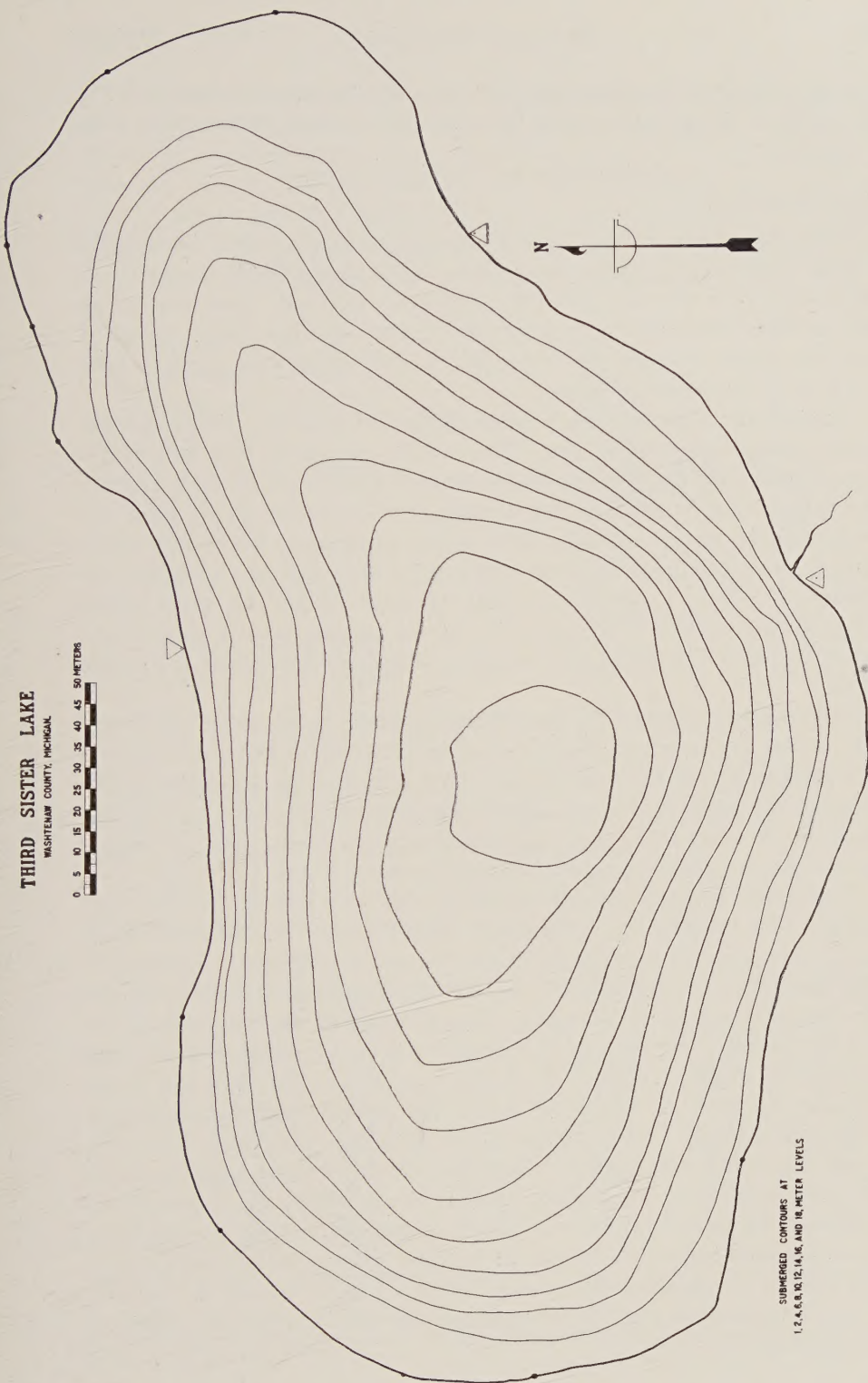
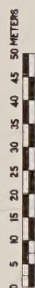
1. A complete vertical series of temperature readings.
2. Samples for dissolved oxygen at intervals selected according to conditions of temperature distribution.
3. Determinations of pH and free carbon dioxide with freshly collected samples during the digestion period required in the oxygen analyses.
4. Collection of another set of samples for determining phenolphthalein and methyl orange alkalinity.
5. If on the program for the day, vertical catches with a closing plankton net to determine the presence or absence of *Corethra* larvae in the water.
6. Bottom sampling.

Experimental

Considerable experimental work was carried on in the lakes themselves and for this purpose it became necessary to sink certain apparatus to the lake bottom. A plan for supporting experimental boxes on the lake floor, or at any desired level in the lake, was devised in the spring of 1927 (Fig. 62). Perhaps the most important advantage of this arrangement is the possibility of raising and examining any one experimental box without disturbing the others or the anchors. In these experiments, use has been made of galvanized wire baskets as receptacles for holding the various glass containers in which experimental animals were placed. Further details of the experiments and their conduct will be found in the section where the results are discussed.

Besides the experiments on the lake floor, a certain amount of such work has been done in the laboratory, some of which involved the use of various constant temperature devices. Low temperatures were secured by using a circulating brine system and high temperatures by employing a DeKotinsky

THIRD SISTER LAKE
WASHTENAW COUNTY, MICHIGAN



SUBMERGED CONTOURS AT
1, 2, 4, 6, 8, 10, 12, 14, 16, AND 18 METER LEVELS

FIG. 1. Map of Third Sister Lake. The small triangles on shore indicate position of permanent monuments over which the transits were located. The dot within the triangle indicates the exact location of the monument.

Constant Temperature Apparatus. During the toleration experiments (Fig. 63) tanks of compressed oxygen, hydrogen and carbon dioxide were used.

PHYSIOGRAPHY AND MORPHOMETRY

Third Sister Lake

West of Ann Arbor, Washtenaw County, Michigan, are three small bodies of water known as the Three Sister Lakes. The largest of the group, Third Sister, is the only one with which this report is concerned. It is deep for its size, stratifies thermally in summer, and drains into the Great Lakes-St. Lawrence system through the Huron River. The latter stream enters Lake Erie near its northwestern corner.

Third Sister Lake has two possible sources of inflowing water and one certain, though intermittent, one. There is the possibility that part of the water coming into the lake reaches it through springs on its floor and the apparently stronger possibility that seepage from bordering boggy areas and surrounding higher ground adds more water, while every heavy rain transforms the, at other times dry, creek entering on the south into a raging little torrent. The heavy loads of suspended substances which this small stream brings down from the cultivated fields on the adjacent kames play an important part in the character and the rate and mode of deposition on the lake bottom.

There is a single outlet flowing through a small marsh southwest of the lake. About one-fourth of the shore is firm and composed of sandy gravel; the remainder is very soft and muddy with a semi-floating mat of sphagnum bordering the water line along part of the western end. Mixed with the sphagnum are many other plants typical of such situations. The submerged and emergent vegetation zone extends approximately to the 3 m. depth.

When work was begun, only an outline map of Third Sister Lake was available. To complete the study and to form the basis for computations, a detailed and accurate hydrographic map became a necessity. The instruments used were two transits and one surveying compass. In mapping the shore line, 60 positions were chosen; bearings taken on them by each of the three instruments; and the angles later protracted. To check on the outline thus secured, 10 points, marked by small solid circles on the shore line of the map (Fig. 1), were determined by actual measurement with steel tape over the ice in mid-winter. Computations based on a large map, scale of 1:250, showed that differences between results secured by the two methods in no case exceeded 0.15 m. For present purposes this is sufficiently accurate since fluctuations of water level exceed 0.25 m. Computed and measured lengths of the base lines were also checked in the same manner and found to agree more closely, the greatest discrepancy between results secured by the two methods being about 0.1 m. Submerged contours are based on approximately 200 soundings.

The only morphometric data on Third Sister Lake which the writer has seen in print are contained in a paper by Weld (1904, p. 38). This author gives the elevation of the three lakes in the group as "approximately the same, *i.e.*, 914 ft. (278 m.) above sea level" and states on the same page, that, "The depth of the lakes varies with the size, the first being 18 ft. (5.5 m.) deep . . . and the third 55 ft. (16.75 m.)." Evidently the deepest part of the lake had not been found at that time, since a considerable area is 18 m. or more in depth.

Maximum length	310 m.
Maximum breadth	150 m.
Maximum depth	18.5 m.
Mean depth ¹	7.35 m.
Direction of main axis	northeast and southwest
Area	38,500 sq.m.
Elevation	278 m.
Length of shore line	863 m.
Shore development	1.24
Volume	283,153 cu. m.
Volume development	1.22
Mean slope of bottom ²	1.3%

There is but one depression, nearly centrally located, in this lake. The general shape of the basin is that of a scoop, being shallow in the eastern portion, quite generally deeper in the western end and deepest somewhat west of the center. The slope of the bottom is gentle in the eastern part and moderately steep along the southern and western sides.

TABLE I. *Areas and volumes of the water at various levels Third Sister Lake.*

Depth meters	Areas		Stratum meters	Vol. each stratum cu. m.	% of Total vol.	Underlying vol. in % of Total
	Sq. meters	% of surface				
0.....	38,500	100	0-1	34,612	12.22	87.78
1.....	30,866	80.2	1-2	28,996	10.24	77.54
2.....	27,166	70.6	2-4	50,705	17.90	59.64
4.....	23,582	61.3	4-6	44,250	15.63	44.01
6.....	20,700	53.8	6-8	37,759	13.34	30.67
8.....	17,116	44.4	8-10	30,456	10.76	19.91
10.....	13,416	34.8	10-12	23,296	8.23	11.68
12.....	9,966	25.9	12-14	16,879	5.96	5.72
14.....	7,000	18.2	14-16	11,045	3.90	1.82
16.....	4,167	10.8	16-18	5,155	1.82	0.00
18.....	1,267	3.3				

¹ Also called "reduced thickness."

² The figures indicated by footnote references 1 and 2 were computed with formulae given by Juday (1914; p. 122).

TABLE II. *Areas of the bottom at various levels Third Sister Lake.*

Depth meters	Length of contour meters	Stratum meters	Area between contours sq. meters	% of total bottom area
0.....	863	0-1	7,634	19.8
1.....	750	1-2	3,700	9.6
2.....	713	2-4	3,584	9.3
4.....	680	4-6	2,882	7.5
6.....	643	6-8	3,584	9.3
8.....	595	8-10	3,700	9.6
10.....	518	10-12	3,450	9.0
12.....	425	12-14	2,966	7.7
14.....	345	14-16	2,833	7.4
16.....	263	16-18	2,900	7.5
18.....	135	18-18.5	1,267	3.3
Totals.....	—	—	38,500	100.0

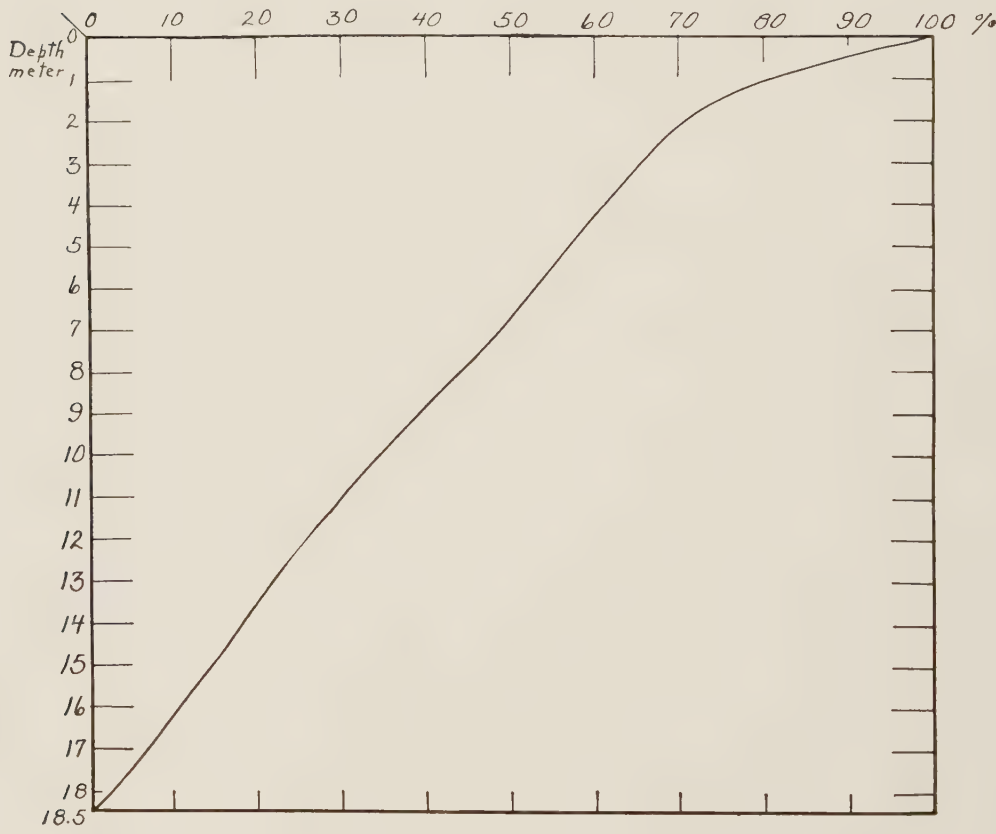
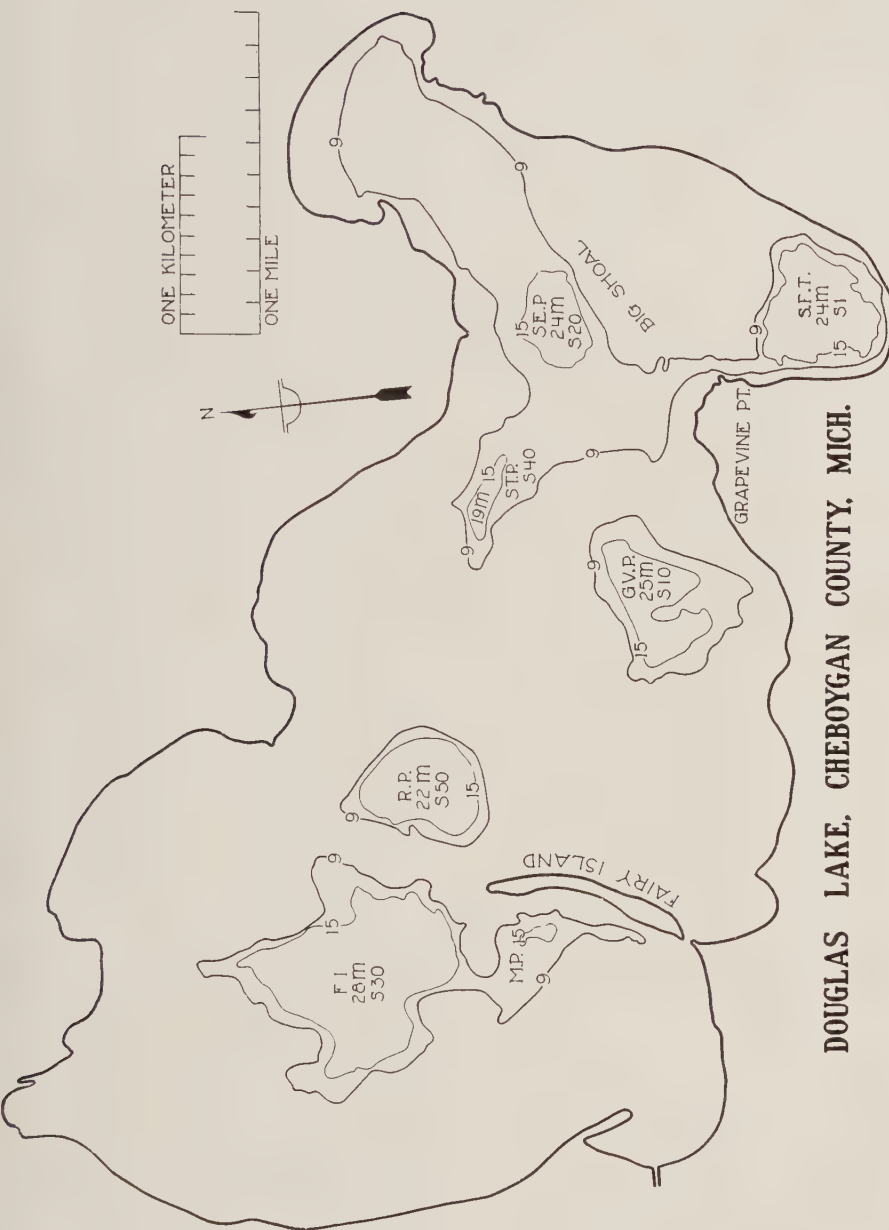


FIG. 2. Curve showing area of lake basin at any depth as a per cent of area of surface.



DOUGLAS LAKE, CHEBOYGAN COUNTY, MICH.

FIG. 3. Map of Douglas Lake. Position of the seven depressions, maximum depth of each in meters, station number of each depression, and extent of the profundal (15) and the sublittoral (9) zones are indicated as follows: F. I., 28 m., S30, Fairy Island depression, maximum depth 28 m., Station 30; R. P., 22 m., S50, Roberts Point depression, maximum depth 22 m., Station 50; G. V. P., 25 m., S10, Grapevine Point depression, maximum depth 25 m., Station 10; S. T. P., 19 m., S40, Stony Point depression, maximum depth 19 m., Station 40; S. E. P., 24 m., S20, Sedge Point depression, maximum depth 24 m., Station 20; S. F. T., 24 m., S1, South Fish-Tail depression, maximum depth 24 m., Station 1; M. P., Maple Point depression. The area included within the 15 meter contour indicates profundal zone, that between 9 and 15 meters the sublittoral, and the region between the shore line and the 9 meter contour represents the extent of the littoral zone.

Douglas Lake

This body of water is located near the northern tip of the southern peninsula, Michigan, approximately 15 miles south of the Straits of Mackinac and about midway between Cheboygan on Lake Huron and Petosky on Lake Michigan. It is a moderately deep lake of glacial origin, showing typical thermal stratification, with certain exceptions discussed by Welch (1927). It empties into Lake Huron through the Cheboygan River drainage. Scott (1921, pp. 106-117) discussed the geological history and physiography of Douglas Lake and Welch (1927) has given in summarized form a large amount of morphometric data. In the present paper, areas of certain subdivisions of the lake bottom are given in greater detail. The hydrographic map from which this information was derived and from which data have been taken for constructing the outline map of the lake included herein, was made by the Department of Geodesy and Surveying, University of Michigan.

None of the depths given in this paper are referred to standard low water datum but all are given as average depths recorded in various depressions and stations at the time of sampling. Thus the maximum depth of Douglas Lake, standard low water datum, is 89 ft. (27.1 m.), but throughout this paper the greater depth of 28 m. is used. This procedure seems preferable

TABLE III. *Area of bottom at various levels in the six major depressions and in the inter-depression regions of Douglas Lake.*

Depression	Depth meters	Length of contour meters	Strata meters	Area between contours square meters	% total bottom area
South Fish-Tail*.....	9.14	2,784	9-15	128,636	0.85
	15.24	2,304	15-24	246,515	1.63
Grapevine Point.....	9.14	2,832	9-15	232,121	1.53
	15.24	2,448	15-25	181,818	1.20
Sedge Point.....	9.14	6,480	9-15	1,187,878	7.87
	15.24	1,392	15-24	124,091	0.82
Fairy Island.....	9.14	4,992	9-15	290,909	1.93
	15.24	3,648	15-28	562,424	3.72
Stony Point.....	9.14	1,920	9-15	116,818	0.77
	15.24	960	15-19	35,000	0.23
Roberts Point.....	9.14	2,256	9-15	93,939	0.62
	15.24	1,776	15-22	214,545	1.42
Whole Lake.....	0.0	25,123	0-9	11,517,733	76.27
	9.14	23,808	9-15	2,206,210	14.62
	15.24	13,056	15-28	1,375,757	9.11

9.14 meters (30 feet)

15.24 meters (50 feet)

*In earlier work on Douglas Lake, e.g. (Welch, 1927) this region of the lake has been called "Camp Davis depression." Since that time the name has been officially changed to "South Fish-Tail depression."

for the purposes of this particular study since it is depth of water at a given time and not the lowest level recorded which is of importance to the bottom animals then being studied.

One very distinctive feature of Douglas Lake is the peculiarity of its basin. Scott (*loc. cit.*) calls attention to the apparent division of the lake into three basins and Welch (1927) further discusses the lake floor and points out that actually there are seven distinct basins or depressions in the lake aside from the deeper water of North Fish-Tail Bay. It is further pointed out by the latter author that these depressions are isolated from each

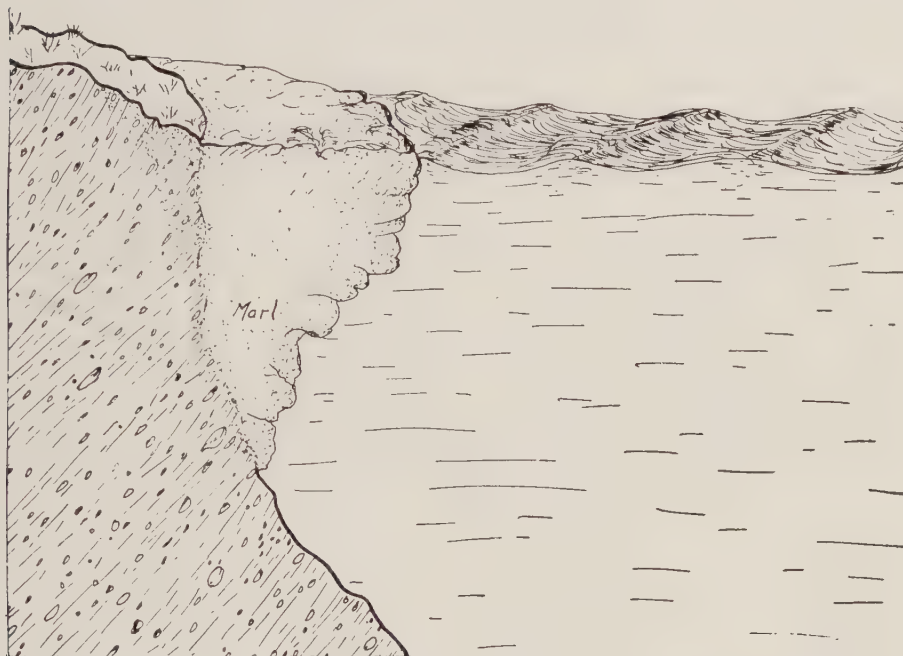


FIG. 4. Diagrammatic sketch showing marl shelf on shore of Kirkville Green Lake.

other by depth contours of 40 ft. (12.19 m.) or less and that they behave, in a physical-chemical sense, as separate lakes. The biological importance of this phenomenon will receive some discussion in this paper.

Kirkville Green Lake

Kirkville Green Lake is located in Onondaga County, New York, approximately 1.5 miles southwest of Kirkville, 10 miles east of Syracuse and about 9 miles south of Oneida Lake, into which it empties through a tributary of Chittenango Creek. It is thus within the Great Lakes water-shed. The lake is scarcely more than 0.5 mile long but attains the surprising depth of 61 m. Due to this, and to the fact that it is unusually well protected from wind in all but one direction, it exhibits certain physical, chemical and biological features which make it very interesting.

Hardly less remarkable than the intense bottle-green color of the water over the depths is the size of the marl deposits along the banks and on the lake floor. The writer has taken marl incrustations 10 cm. thick from a depth of 2-3 m. Frequently, cylindrical incrustations, 15-16 cm. in diameter, were brought up which, when broken open, were found to be deposited upon a twig perhaps 5 mm. in diameter. Solid banks of marl occur along shore and in some places these appear to be several meters thick. In at least one place an overhanging shelf of creamy-white marl has been built out from shore with its upper surface just beneath the water level and its edge more than 2.5 m. from the bank. This shelf tapers back at its base and thus has the form shown in diagrammatical cross-section in Fig. 4.

Except for a narrow beach extending across the northern end of the lake, there is no submerged shelf and the bottom drops precipitously into deep water from the shore line. It is possible to stand on the marl deposit extending out from the bank at one point on shore and drop a sounding lead over the edge to a depth of 18 m.

It should be pointed out that none of the lakes studied are in any sense contaminated or polluted bodies of water. At least one has been considered as a source of water supply for a neighboring city. Each is as nearly unmodified as a lake is apt to be in settled regions. There are no industrial wastes emptied within the area drained by any of them and in the case of one there are no dwellings within 0.5 mile of its shores. Douglas Lake has a few summer colonies and the University of Michigan Biological Station on its shores, and the others are bordered by farm lands.

ACKNOWLEDGMENTS

Many people have assisted the writer in various ways during this investigation and such service is here gratefully acknowledged. The work has been done under the general direction of Professor Paul S. Welch. To Director George R. LaRue, the writer is indebted for the use of facilities at the University of Michigan Biological Station. Thanks are also due to Dean Samuel T. Dana and other staff members in the University of Michigan School of Forestry and Conservation for many courtesies extended to the author in connection with the study of Third Sister Lake; to Professor William M. Smallwood and the Department of Zoölogy, Syracuse University, for the use of facilities while work was in progress on Kirkville Green Lake, and to the following authorities for identification of specimens: Professor O. A. Johannsen, *Chironomidae* and *Culicidae*, both immature and adults; Professor Frank Smith, *Oligochacta*; Dr. V. Sterki, *Sphaeriidae*; Dr. Bryant Walker, *Gastropoda*; Dr. Ruth Marshall, *Hydracarina*; Dr. J. Percy Moore, *Hirudinea*; Dr. L. J. Thomas; *Mermithidae*; and Dr. N. A. Cobb, free-living *Nematoda*.

PROFUNDAL BENTHIC HABITAT

GENERAL STATEMENT

Ecologically, a lake may be divided into two regions, the limnetic and the benthic. Each has its own set of peculiarly characteristic phenomena. The physical, chemical, and biological factors of the lake bottom are, moreover, far from uniform from shore to lake center and this lack of uniformity results both in the need for and the means of further subdivision and a classification of benthic habitats.

CLASSIFICATION OF BENTHIC HABITATS

At least 3 distinct major zones may be recognized readily on the lake-floor: littoral, sublittoral and profundal. A fourth, the "abyssal" is considered by some to occur in the deepest lakes, beginning at approximately 600 m. (Carpenter, 1928; p. 180) and extending to the greatest depth. The relative extent of these zones in different lakes varies to a marked degree, and indeed in some lakes the whole bottom may be said to be within the littoral. Muttowski (1918, pp. 378-381) gave a classification of both limnetic (pelagic) and benthic habitats and proposed several terms to replace those which, perhaps, had been borrowed from oceanography. As yet his proposals have not been generally adopted by limnologists. Some other authors use such descriptive terms as "shallow water zone," "intermediate zone," and "deep-water zone." Lundbeck (1926, p. 116) summarizes the classification of bottom habitats by various authors, accepts the three terms, littoral, sublittoral and profundal and compares the extent of these zones as variously defined by himself and by others. It is not the purpose of the present writer to attempt to decide the relative merits of these various systems of terminology. But until some definite agreement has been reached by limnologists in general with respect to them it may perhaps be as well to use the older and more generally accepted ones, if only in the interest of uniformity.

In this paper, the littoral zone of the bottom is understood to mean that region lying between the shoreline and, approximately, the lakeward limit of aquatic vegetation. The profundal zone extends from the greatest depth (in lakes here considered) up the slope toward shore to a point somewhat above that corresponding to the average upper limit of the hypolimnion. The sublittoral lies between these two.

In Douglas Lake the littoral zone would thus extend from the shore line to a depth of about 9 m., the sublittoral, 9-15 m., while the profundal includes all the bottom below the latter depth, 15-28 m. In Third Sister Lake the three major benthic zones have the following approximate extent: littoral, 0-3 m.; sublittoral, 3-10 m.; profundal, 10-18 m. Kirkville Green Lake has a narrow littoral zone which probably in no place extends below 3 m.; the sublittoral may reach to 6 or 8 m.; and the profundal (8-61 m.) would thus cover by far the larger portion of the bottom.

BOTTOM DEPOSITS

The bottom within the littoral zone in Douglas Lake is predominantly sandy. The submerged terrace which occurs around practically the whole shore is built almost entirely of sand, except where headlands jut into the lake as at Grapevine, Stony and Roberts Points and at Fairy Island. At these places the shelf is composed of gravel, cobblestones, and small boulders mixed with the sand. The principal vegetation region of the lake is in the western end, where, protected from strong wave action induced by prevailing northwesterly winds, emergent and submerged vegetation has reached its richest development. Except for a fairly extensive area of *Scirpus validus* Vahl. on Big Shoal and some other, minor, exceptions in small coves, vegetation in the eastern part of the lake is confined to the usually steep slopes extending downward from the edge of the submerged terrace. Only in rare instances has the writer brought up bottom samples from below 9 m. which contained any living plants. The whole central portion of the lake, bordered by Grapevine Point, Sedge Point and Stony Point depressions on the east and by Roberts Point depression and Fairy Island on the west, is shallow and lies partly within the littoral and partly within the sublittoral (Fig. 3). Much of this region supports a considerable growth of submerged vegetation and over the entire area bottom deposits are sandy mud. Both in this central region of the lake and within the sublittoral on the slopes of the depressions there are evidences of a weakly developed shell zone.

The sublittoral is truly a transition zone in Douglas Lake. Bottom deposits within it are characterized by a change from the sand of the littoral to the mud of the profundal. In North Fish-Tail Bay, where the slope is not so abrupt as in many parts of the lake, the change from a distinctly sandy bottom to a distinctly muddy one takes place between depths of 9 and 11 m. Repeated sampling in series, usually beginning where the water was about 5 meters deep, and extending to the center of the bay, showed clean sand up to depths of 8 or 8.5 m.; the first noticeable amounts of mud at 9 m.; muddy sand at 9.5-10 m.; sandy mud, 10-11 m., and beyond that depth no noticeable amounts of sand. In small, more protected coves, mud extends to shallower depths and there vegetation attains its best development.

Around the edges of all major depressions, sand persists in considerable amounts down to a depth of 15 m., and along the eastern side of Sedge Point depression, the bottom consists of muddy sand as far down as 21 m. This may be due to carrying of sand into the depression by undertow currents off of the Big Shoal. In Maple Point depression, located just west of Fairy Island, the author has never found anything but clean or slightly muddy sand on the bottom.

The lake floor of the profundal zone, which in Douglas Lake occurs entirely within the major depressions, is carpeted with a thick layer of fine,

black ooze. Superficially, this mud appears to be homogeneous in texture and of a uniform character in each of the depressions. Welch (1927, p. 430-431) points out the fact of depression individuality in regard to physical-chemical conditions of the water, and early in the present work certain well marked differences, principally quantitative, were noticed in the bottom fauna of the six deeper depressions. The question as to whether this depression individuality also extended to bottom deposits naturally arose. Accordingly, two series of samples, all of equal volume, were collected near the center of each area of deeper water and examined. In collecting mud, the dredge was allowed to settled through the watery upper layer into firmer mud beneath.

One series of samples was put through a set of 6 Tyler screens to determine amount and character of coarse parts of the mud. Table IV presents data obtained from examination of mud collected in South Fish-Tail depression. However, mud from each of the other depressions, from the

TABLE IV. *Physical examination of bottom mud. Samples taken from the center of South Fish-Tail depression at 23 m. depth.*

Tyler Screen No.	Size Mesh mm.	% Passing through	Color and consistency of part remaining in screen
1	4.699	99	Black. Mostly plant materials. Leaves, etc.
2	2.362	98	Black. Plant and animal remains. Bits of leaves; plant fibers, fish scales and bones, etc.
3	1.168	90	Black. Mostly plant fibers.
4	0.417	85	Black. Fine debris of plant and animal origin.
5	0.208	80	Black. Very finely divided organic matter of plant and animal origin.
6	0.147	70	Black. Extremely finely divided organic matter of animal and plant origin, mixed with finely divided inorganic "dust."

deeper water of North Fish-Tail Bay, and from Grapevine Channel—the narrow neck of deep water between Grapevine Point and Big Shoal—was also examined in the same manner. The relative proportions of coarser debris (that part retained by the complete set of screens) and dust fine detritus (that part passing through the finest screen) remained, however, fairly constant. The percentage passing through the finest screen varied from 68.7 in Sedge Point depression to 74.4 in Fairy Island depression, an extreme variation of only 5.7 per cent. Table IV shows that 10 per cent of the mud is relatively coarse and consists of bits of both plant and animal remains, 20 per cent is finely divided organic material but still not fine enough to pass through a screen with 100 meshes per inch (0.147 mm.), while the remaining 70 per cent constitutes the dust fine detritus referred to above. Practically all inorganic material in the profundal mud is contained in this extremely finely divided matter.

The second series of samples was used for the purpose of determining (1) weight per unit volume of wet mud, dry mud, residue after ignition, and loss on ignition; and (2) percentage of water and solid matter in the wet mud, and percentage of volatile and non-volatile matter in the dry mud. Table V gives details of this analysis. The samples of wet mud were placed in previously weighed, wide mouth jars. These were tightly closed in the field. Later, in the laboratory, the wet mud was weighed on heavy analytical balances and then dried in an electric oven at 60°C. for 96 hours. The dry mud was then cooled in a dessicator; weighed on a delicate analytical balance to the nearest whole milligram; ashed in a fused silica crucible over a gas blast lamp for 40-50 hours; again cooled in a dessicator; and finally the ash (residue after ignition) weighed on an analytical balance. The difference between weight of the dry mud and weight of the residue after ignition (*i.e.*, loss on ignition) represents approximately the weight of the dry volatile matter, and the weight of the ash represents non-volatile matter present in the dry mud. Table V also gives data for Third Sister Lake which will be discussed later.

It is evident that bottom deposits are not uniform in all depressions of Douglas Lake. The muds from South Fish-Tail and Fairy Island depressions are most alike and this similarity may be due to the protected position of the former and the large size of the latter, since both factors would tend to minimize the amounts of heavier inorganic matter carried into the center of the depressions. Differences of bottom deposits in various depressions in terms of weight of dry mud, ash, and loss on ignition, and in ratios between water and solids and between volatile and non-volatile matter are not great when mud from a given depression is compared with that most like it. But if, on the other hand, the greatest differences be sought, as for instance, those between the mud from South Fish-Tail depression and that from Stony Point depression, then some appearance of depression individuality is evident. This is more significant when it is pointed out that the samples analyzed were portions of thoroughly mixed larger samples composed of 5 dredge-fulls of mud taken from widely scattered points within the deepest water area.

The floor of Third Sister Lake is predominantly muddy. There is a short stretch of about 100 m. along the southeastern shore where the bottom is firm and contains some sand and on the northern side there is a shorter reach of firm bottom along shore. Aside from these two regions, bottom deposits are largely mud from shore to lake center. Differences between the bottom within the littoral and the profundal zones, which are so pronounced in Douglas Lake, are not nearly so great in Third Sister. In the latter, the plant zone is largely restricted to the area above the 2 m. contour with scattered patches of vegetation extending to a depth of 3 m. There is a weakly developed shell zone in isolated spots within the sublittoral, located most often at a depth of 5-6 m., and also within this zone bottom deposits lose all littoral characters

and change to a stratified mud which covers all the bottom below the 10 m. contour.

The stratification of bottom deposits within the profundal zone of Third Sister Lake is one of the most apparent of their characteristics. If a sample of this bottom mud is carefully removed from the dredge it will retain, very nearly, the shape of the dredge opening and will show, on its edges, clearly defined alternate layers of a soft, black, organic detritus and a much firmer grayish clay. The thickness of these two kinds of layers was measured in many samples, and, although there was much variation, the average thickness may be stated as about 1-2 cm. for the clay strata and 0.5-1 cm. for the ooze layers. The dredge ordinarily penetrated to a depth of only about 8-10 cm. in the relatively firm mud and no increase in density of the lower layers could be discovered in this slight thickness.

The clay strata of this bottom mud are so firm and sticky that they can, with a little care, be separated from the ooze layers and in this way it is possible to get practically pure samples of each layer. The last 3 lines of Table V show results of analyses of (1) bottom mud as it occurs in the lake (1a), *i.e.* alternate layers of clay and ooze, which for purposes of analysis were thoroughly mixed together; (2) the organic detritus layers (1b), and (3) the clay strata (1c). The results from the mixed mud show a very surprising approximation to the average of the values for the two layers taken separately. While it is true that the two kinds of material were present in about equal proportions, by volume, this striking similarity of the mixture to the mean of its two parts is almost certainly accidental in the case of these data. Many analyses would be needed before any such close agreement could be shown to be constant or even usual. However, as in the instance of the Douglas Lake mud, these samples were parts of larger, composite samples which were collected from various points within the 18 m. contour and hence the data have a reasonable validity.

Reference to Table V will show that the black detritus layers are somewhat like the profundal bottom deposits of Douglas Lake, the percentage of organic matter being most nearly like that in the South Fish-Tail depression mud and the ratio between solid matter and water in wet mud at least comparable to the Stony Point depression mud. The clay strata, however, are entirely unlike anything found in Douglas Lake and this difference is so pronounced that mud taken as it occurs on the lake floor (1a) is also greatly different than any profundal mud in Douglas Lake.

Evidence from several sources seems to indicate that the clay strata are deposited largely during the spring and that the black detritus layers are laid down during the rest of the year. The explanation is two-fold. Deposition of black ooze probably goes on throughout the year, but is perhaps greatest during summer and autumn. Repeated observations at all times of the year and extending over several years have shown that the small intermittent

stream entering the lake carries very heavy loads of clay and silt. Some material of this nature is thus brought into the lake from the time ice disappears in the spring until it forms again in early winter. This is reflected in the detritus layers which, themselves, are made up of mud that is heavier than the heaviest from Douglas Lake. But in summer and autumn the fields are covered with vegetation, and this fact, possibly together with others, greatly reduces the amount of clay brought into the lake by the creek during these seasons. On the other hand, the thaws of late winter and the heavy rains of spring find the fields bare of vegetation and it is then that relatively very large amounts of clay are carried into the lake.

Direct evidence, from field observations, shows that the ice is frequently coated with a layer of clay, deposited when the surface is flooded by the first thaws of late winter. This load is, of course, dropped into the lake when the ice melts. Furthermore during the spring the creek is seldom dry, its waters are very muddy, and the whole body of the lake is frequently so turbid for days at a time that Secchi's disc cannot be seen below 1 m., whereas the disc reading during other seasons of the year averages about 5 m.

Bottom deposits of other lakes considered in this investigation received only casual study, but the following observations seem worthy of inclusion. The most characteristic thing about the shallow water bottoms in Kirkville Green Lake is the extensive deposits of marl. In the deep water (below 15 m.) the bottom is composed of a fine, black ooze which has a distinctly greasy feeling and a very offensive odor.

SUPERIMPOSED WATER

The relation of superimposed water to profundal benthic habitat is an important one in lakes of the type studied; *i.e.*, those which typically show thermal-chemical stratification in summer. In any attempt to determine extent of the various benthic zones, the physical-chemical conditions, as imposed by thermal stratification of the water are perhaps the most important factors. Certainly this is true so far as the profundal region is concerned. Plant growth is a useful and significant criterion in the upper zones and bottom deposits must be considered at all levels, while depth, although influencing all the other factors, is not, of itself, a constant or dependable index, since the ratios between it and other factors vary greatly in different waters.

In the lakes on which this study has been conducted, the typical profundal benthic habitat is understood to mean, in general, that region of the lake floor which lies beneath the hypolimnion and is therefore subjected to continuously low temperatures; little or no light; a pH which frequently falls below neutrality; considerable amounts of free carbon dioxide; a complete absence of dissolved oxygen during part of the summer and often during late winter; and, at least in some lakes, accumulations of methane, hydrogen sulfide, and perhaps other decomposition gases.

The upper limit of the hypolimnion in Douglas Lake varies somewhat with the time of year and from season to season; and it frequently is different in each depression. However, if all the data available on all the depressions are considered, the average for the whole lake over a period of years is near 15 m. Tables 6-11 give, in summarized form, data on the 6 major depressions of this lake for the years 1923, 1926, 1927 and 1928. It will be seen from these tables that, excepting Stony Point depression which is the shallowest of the six and which frequently does not stratify thermally, the bottom beneath the hypolimnion is a region subjected to typical profundal conditions.

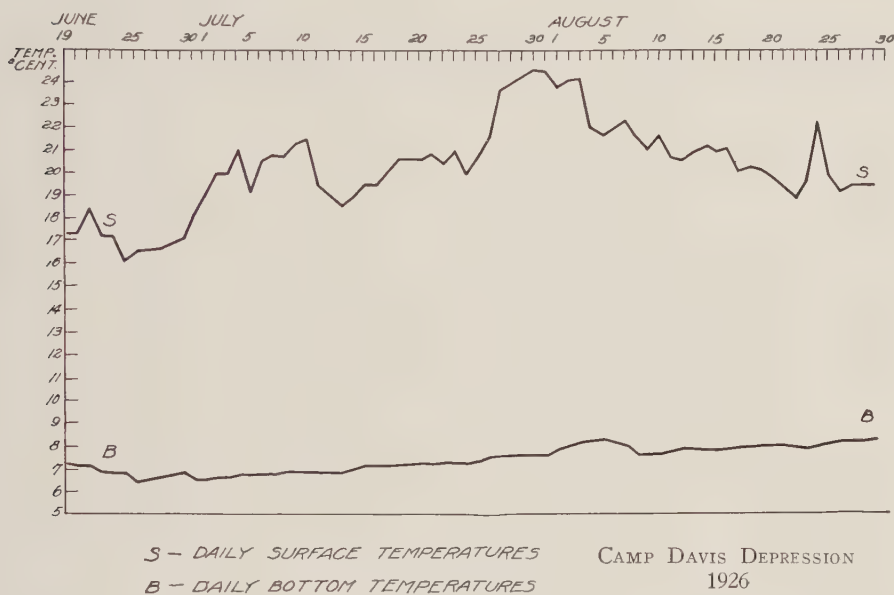


FIGURE 5

Figure 5 gives daily surface and bottom temperatures, taken in South Fish-Tail depression during 1926. The increase in temperature of the bottom mud during the summer is slight. It may be pointed out that the increase is continuous and steady and that it lags slightly behind a similar rise in temperature of the bottom water. The figure shows clearly the comparative uniformity of low temperatures at the bottom.

The deeper waters of Third Sister Lake show a seasonal cycle of physical-chemical phenomena which approaches even more closely that of the theoretically typical stagnation zone. A summary of the data concerning temperature, pH, dissolved oxygen and free carbon dioxide, at the surface, upper limit of the hypolimnion, and at the bottom, on selected dates in 1923, and between October, 1926, and February, 1929, is given in Table XII. Thermal stratification of this lake probably begins much earlier in the spring than in Douglas



FIGS. 6-11. Temperature distribution in Kirkville Green Lake on selected dates in 1925. Depths in meters and temperatures in degrees Centigrade.

Lake and the few available fall records for the latter (Tables VI and XI; October 20, 1928) indicate that the period of summer stagnation also persists longer in the fall. Here again, occurs a typical profundal benthic habitat and, coincident with a longer period of stagnation, physical-chemical conditions on the lake floor beneath the hypolimnion are even more severe than in Douglas Lake. The shape of the basins, the character and distribution of the plants, the nature of the bottom deposits and of the waters indicate that Douglas and Third Sister Lakes belong to the type often designated as *eutrophic*.

Kirkville Green Lake is roughly flask-shaped. The body of the lake and one side of the neck are surrounded by high, wooded bluffs and it is thus unusually well protected from wind disturbance. Indeed, even when relatively high winds are blowing, its surface is scarcely more than rippled. This fact, together with the steep slope of its floor, the black, greasy character and the foul odor of its deeper mud deposits (over which it was at times impossible to work more than a few minutes without becoming nauseated) and the peculiarities of its temperature distribution (Figs. 6-11; Table XIII) leads the author to suspect that the lake may have incomplete spring and fall overturns. It may even be possible that complete circulation is wholly absent. If this be true, stagnation would become particularly effective and, not being relieved by the usual semi-annual circulation periods, would produce a profundal benthic habitat of the most severe sort.

Some features of Kirkville Green Lake, such as its steeply sloping bottom, its clear water, and the slight development of its littoral zone, would seem to place it in the *oligothropic* class. Other characters, just discussed, perhaps indicate that its profundal zone is more nearly like that of the *dystrophic* lakes.

PROFUNDAL BOTTOM FAUNA

GENERAL FEATURES

On a qualitative basis, the bottom samples collected must be considered in two groups. In one group are those which were taken in sampling series extending from deep to shallow water. Usually such series were begun in the deepest water and, with samples taken at frequent intervals, extended as far up the slope as any profundal bottom animals were found. Sometimes such series were continued into shallower water, and in some instances a certain amount of sampling was done wholly in moderate depths. The animals secured in these samples, obviously, would not form a homogeneous group, but, instead, changed with the decrease in depth.

The bottom samples taken entirely within the true profundal zone form the other natural group. Here the organisms secured constitute a somewhat homogeneous and very distinct ecological association. This fauna is qualitatively poor but quantitatively very rich. It makes up the typical profundal bottom fauna and includes representatives of the genera *Corethra*, *Chi-*

ronomus, and Protenthes, among the Insecta; Limnodrilus among the Oligochaeta; Pisidium and Musculium among the Mollusca; and Hydromermis from the Nematoda. In the following section this last group will be considered first.

These types, and particularly representatives of the genera Corethra, Chironomus, and Protenthes and of the family Tubificidae, constitute a truly typical, profundal, benthic fauna in the lakes studied. This fact is clearly shown by Tables XIV-XVII, which give the seasonal variations of the bottom animals below 21 m. in South Fish-Tail, Sedge Point, Fairy Island, and Roberts Point depressions of Douglas Lake. Table XX gives similar data on bottom fauna below the 18 m. contour in Third Sister Lake. It will be seen that in each of these tables the column headed "all others" is, with certain exceptions to be discussed later, a record of an almost complete absence of any other animals. The fact that these animals occur in the sublittoral of both Douglas and Third Sister Lakes, as well as in the profundal, and the additional fact that some of them were found in the littoral zone in certain other lakes, do not render unsound their classification as profundal. They are here considered as constituting the typical profundal benthic fauna of the lakes studied, because they are the only benthic animals typically found within the true profundal zone during the time when the environmental factors which make it a profundal zone are at their maximum intensities.

ANNOTATED LIST

Notes included within quotation marks are quoted from comments written on the lists of identifications by the authorities who identified the specimens.

Typical Profundal Fauna

INSECTA

1. *Corethra punctipennis* Say. Professor Johannsen, in his list of identifications gave Chaoborus as the name of the genus and Corethra as a synonym. The author, however, prefers to use the better known name, Corethra, for reasons which need not be discussed here.

Larvae one of three most abundant organisms within true profundal zone; in all depressions of Douglas Lake, usually in all depressions at same time; never entirely absent from profundal zone in Third Sister Lake, at times in very large numbers; sometimes many larvae in water over this zone; frequently limited numbers in sublittoral zone of Douglas and Third Sister Lakes; not taken in littoral zone except when washed ashore by heavy on-shore night winds. Never found in Kirkville Green Lake. Only one species.

2. *Chironomus plumosus* L. Common within profundal, Douglas Lake; 12-28 m. Rare in Third Sister Lake; taken only at 10-12 m. Larvae C.

plumosus and *C. plumosus* var. *ferrugineovittatus* constituted greater part chironomid fauna within profundal zone in Douglas Lake.

3. *Chironomus plumosus* var. *ferrugineovittatus* Zett. Douglas Lake; slightly less numerous than *C. plumosus* in profundal zone; in all depressions and in deeper water, North Fish-Tail Bay. Not known from other lakes studied.

4. *Chironomus utahensis* Mall. Third Sister Lake, 8-18 m.; most common below 10 m. Larvae of this species and of *C. fasciventris* constituted practically all chironomids within profundal zone in Third Sister Lake. Not known from other lakes investigated.

5. *Chironomus fasciventris* Mall. Taken only in Third Sister Lake; 6-18 m., most numerous 6-12 m.; apparently outnumbered by *C. utahensis* approximately 2:1 within entire profundal zone.

6. *Protenches culiciformis* L. Larvae in all depressions, Douglas Lake; 10-28 m.; most common in upper profundal and lower sublittoral. Larvae 3-18 m. in Third Sister Lake.

OLIGOCHAETA

7. *Limnodrilus hoffmeisteri* Clap. Douglas Lake, all depressions; 10-28 m. Third Sister Lake, 3-18 m.

8. *Limnodrilus claparedianus* Ratzel. Douglas Lake, profundal zone; all depressions. Third Sister Lake, 3-18 m.

SPHAERIIDAE

9. *Pisidium compressum* Prime. Douglas Lake, Grapevine Point depression, 24 m.; Roberts Point depression, 17-22 m.; South Fish-Tail depression, 13-23 m.; Grapevine Channel, 11-15 m.; Stony Point depression, 18 m.; North Fish-Tail Bay, 10.5 m.; mid-way between Roberts Point and Fairy Island depressions, 16-17 m. Third Sister Lake, 4-8 m. Most common representative of *Sphaeriidae* within profundal zone, Douglas Lake; never in more than limited numbers.

10. *Pisidium* sp. "Immature, somewhat like *splendidulum* St." Grapevine Channel, 17 m.; South Fish-Tail depression, 18 m., Douglas Lake.

11. *Musculium rosaceum* Prime. Stony Point depression, 17-19 m.; North Fish-Tail Bay, 10-12 m., Douglas Lake. Not common.

12. *Musculium truncatum* Linsley. "Apparently." A few immature specimens, Roberts Point depression, Douglas Lake, 21 m.

NEMATODA

13. *Hydromermis* sp. Douglas Lake; all depressions; Grapevine Channel; deeper water, North Fish-Tail Bay; 11-28 m.; most abundant in Roberts Point, Stony Point and Grapevine Point depressions. Occasionally in Third Sister Lake; 8-18 m.

Other Bottom Animals

The forms listed below are those taken in sampling series extending from deep to shallow water, exclusive of the typical profundal species. Included also are those forms taken in samples wholly from shallow water.

HYDRACARINA

1. *Arrhenurus cardiacus* Mar. Third Sister Lake, 6-12 m.
2. *Arrhenurus rectangularis* Mar. Third Sister Lake, 8-15 m.; 1 specimen.
3. *Diplodontus despiciens* (Müll.). Kirkville Green Lake, 1 m. Third Sister Lake, 6-12 m. "Cosmopolitan."
4. *Forelia liliacea* (Müll.). Douglas Lake, Roberts Point depression, 20 m. Few.
5. *Limnesia histrionica wolcottii* Piers. Third Sister Lake, 6-12 m. Few.
6. *Limnochares aquaticus* L. Kirkville Green Lake, 1 m. "Cosmopolitan."
7. *Mideopsus orbicularis* (Müll.). Douglas Lake, Roberts Point depression, 20 m. "Cosmopolitan species."
8. *Neumania semicircularis* Mar. A "common form." Douglas Lake. Roberts Point depression, 20 m. Third Sister Lake, 8-15 m.
9. *Piona interrupta* Mar. Kirkville Green Lake, 3 m.; Third Sister Lake, 4-18 m.

In Third Sister Lake, this is by far the most abundant hydrachnid, outnumbering all others combined. Writing of this species, Dr. Marshall states: "Known from Canadian and Wisconsin deeper waters. Male, heretofore unknown, occurs in the Third Sister Lake collections."

10. *Piona rotunda* (Kram.). Common in Third Sister Lake; 6-18 m.; Second only to *P. interrupta* in abundance.

11. *Unionicola aculeata* (Koen.) "nov. var." Third Sister Lake, 8-18 m.

Concerning this species Dr. Marshall writes: "Found for the first time in northern Wisconsin, 1928, where it was quite abundant." It was the third most numerous mite in Third Sister Lake collections.

12. *Unionicola crassipes* (Müll.). "Cosmopolitan." Third Sister Lake; 6-15 m. Fairly common.

13. *Unionicola pectinatas* (Wol.). Third Sister Lake; 8 m.

INSECTA

1. *Chironomus cagugae* Joh. Douglas Lake, Grapevine Channel, 12-15 m.; Roberts Point depression, 15-18 m.; South Fish-Tail depression, 15-17 m. Adults frequently resting on surface of water over edge of South Fish-Tail depression, both in early morning and late evening; also common on dock posts at Biological Station.

2. *Chironomus decorus* Joh. 1 specimen, reared from pupa taken from surface of water over Roberts Point depression, Douglas Lake.

3. *Chironomus devinctus* Say. South Fish-Tail depression, Douglas Lake, 15 m.

4. *Chironomus stylifera* Joh. Third Sister Lake, 6-10 m.

5. *Chironomus viridicollis* Vaw. Douglas Lake, South Fish-Tail depression, 12 m.

6. *Johannsenomyia* sp. Larvae relatively common in samples from shallower depths; occasionally in deep water: Roberts Point depression, 21 m.; South Fish-Tail depression, 20 m. Most abundant in North Fish-Tail Bay, Douglas Lake, 10-11 m. Commonly present, Third Sister Lake, 3-8 m.; Occasionally abundant, 7-8 m.

7. *Tanytus basalis* Walley. Douglas Lake; Grapevine Channel, 15-17 m.; few; South Fish-Tail Bay, 13 m., rare; 22 m., 1 specimen.

CRUSTACEA

Ostracoda. Ostracods occasionally in Douglas Lake bottom samples; specimens quite small; few, 13-23 m. Sometimes abundant Grapevine Channel, 12 m. Not common in Third Sister Lake, 3-18 m. Species not determined.

GASTROPODA

1. *Amnicola limosa* (Say). Douglas Lake, Roberts Point depression, 18 m.; North Fish-Tail Bay, 10-12 m.; Stony Point depression, 17-19 m.

2. *Campeloma decisum* (Say). Douglas Lake, Stony Point depression, 13-18 m.; South Fish-Tail depression, 12-13 m.; Roberts Point depression, 10-13 m.; Grapevine Point depression, 10-15 m.; North Fish-Tail Bay, 10-12 m. Third Sister Lake, 3-5 m.

3. *Campeloma rufum* (Haldeman). Stony Point depression, Douglas Lake, 15-18 m.

4. *Goniobasis depygis* Say, "var." Kirkville Green Lake, common around shore to depths of 3 m.

5. *Physa heterostropha* Say. Kirkville Green Lake, east and south of outlet, 1 m. North Bay, most of shore line; few.

6. *Planorbis altissimus* Baker. Douglas Lake, Roberts Point depression, 10-12 m.

7. *Planorbis antrosus striatus* Baker. Kirkville Green Lake, 1-5 m.

8. *Planorbis parvus* Say. Kirkville Green Lake, 1-2 m. Douglas Lake, North Fish-Tail Bay, 4-10 m.

9. *Succinea retusa* Lea. Kirkville Green Lake, near outlet. North Bay, 0-2 m., few.

10. *Valvata sincera* Say. Third Sister Lake, fairly common, 3-7 m., especially along southern and western shores.

11. *Valvata tricarinata* Say. Most frequently collected gastropod in Douglas Lake 10-19 m. All depressions and in nearly all samples from inter-depression regions. Frequent in North Fish-Tail Bay, 4-11 m.

12. *Valvata tricarinata perconfusa* Walker. Kirkville Green Lake along west shore, 1 m. Douglas Lake, North Fish-Tail Bay, 10-11 m.

13. *Valvata tricarinata simplex* Gould. Kirkville Green Lake along west shore, few, 0-2 m.

PELECYPODA

1. *Anodonta marginata* Say. A few on upper slopes, South Fish-Tail, Roberts Point and Stony Point depressions, Douglas Lake, 10-18 m.

2. *Lampsilis luteola* (Lamarck). Occasionally in Douglas Lake bottom samples. South Fish-Tail depression, 11 m.; North Fish-Tail Bay, 10 m.; Roberts Point depression, 12 m.; Grapevine Point depression, 10 m.

3. *Pisidium compressum* Prime, "(?), quite peculiar, a form of *compressum*, or near." Douglas Lake, Grapevine Channel, 11-15 m.

4. *Pisidium imbecille* St. Douglas Lake, North Fish-Tail Bay, 4-10 m.

5. *Pisidium variabile* Prime. "A form." Douglas Lake, North Fish-Tail Bay, 10-12 m.

6. *Pisidium* sp. "Apparently an undescribed species of the *compressum* group." Third Sister Lake, 3-8 m.; rather frequent.

7. *Pisidium* sp. "Apparently near *concinnum* St." Both immature and mature specimens. Third Sister Lake, 4-8 m.

8. *Pisidium* sp. Stony Point depression, Douglas Lake, 18 m.; several very young specimens.

9. *Sphaerium acuminatum* (Prime). Douglas Lake, Roberts Point depression, 10-15 m.; Grapevine Channel, 11-15 m.

10. *Sphaerium* nov. sp. "Near *sulcatum* (Lam.), a new species, not published; from many places in Michigan, etc." Douglas Lake, North Fish-Tail Bay, 10-12 m.; Roberts Point depression, 10-14 m.

HIRUDINEA

No leeches were taken in bottom samples but several specimens representing the following species, were found in wire-netting cages which had been lowered to the bottom of Third Sister Lake during certain lake-bottom experiments.

1. *Erpobdella punctata* Leidy.

2. *Glossiphonia complanata* Linn.

NEMATODA

1. *Dorylaimus* nov. sp. (?) Bottom samples, Grapevine Channel, Douglas Lake: 10-15 m.; common, sometimes abundant, maximum number per sq. m. 770. Occasionally elsewhere in lake: South Fish-Tail Bay, 10-12 m.; North

Fish-Tail Bay, 10-12 m.; Stony Point depression, 12-18 m.; Roberts Point depression, 12-20 m.; Grapevine Point depression, 24 m.

Occasional Records

In addition to the animals referred to in the preceding lists, there are scattered records of many other species. None of them occurred with enough regularity, however, to warrant its inclusion in either of the lists. Among such animals were: larvae of *Sialis infumata*; several species of Ephemera, an occasional trichopteran; a few Odonata nymphs; various naids; and rarely a turbellarian, a fragment of a bryozoan, or of some fresh-water sponge.

COMPARISONS

Compared with that of other North American lakes in which bottom fauna has been studied, the profundal fauna of Douglas Lake resembles more closely, in a qualitative sense, that of Lake Mendota, Lake Wawasee, Lake Winnebago, Lake Simcoe and Lake Okoboji than does that of Third Sister Lake. Both Douglas and Third Sister Lakes have a profundal bottom fauna which is qualitatively different than that of Lake Nipigon, Green Lake (Wisconsin), Lake Ontario, the Finger Lakes of New York and Lake George, although in a general way they also have similarities. If differences of species are disregarded and only genera considered, then the profundal fauna of Third Sister Lake is practically the same as that in Douglas Lake and the lakes with which it is compared above.

In the fact that the most abundant chironomid larvae of its deep-water fauna belong to the *C. plumosus* group, Douglas Lake resembles Lake Pepin (Johnson and Munger, 1930) and the Illinois River and its connecting lakes from Chillicothe to Grafton (Richardson, 1928). Douglas Lake is, however, in no sense a polluted body of water and this fact indicates that *C. plumosus* is not always associated with pollution. This is especially interesting in the light of the great abundance of these larvae found in Lake Pepin and in the Illinois River. So far as its chironomids are concerned, Third Sister Lake, with *C. utahensis* and *C. fasciventris* forming the bulk of that group of profundal benthic animals, is unlike any other lake known to the author.

Corethra punctipennis and *Procladius culiciformis* are present in considerable numbers in the bottom fauna of both Douglas and Third Sister Lakes and in this respect these lakes are like Lake Mendota, Lake Simcoe, and Lake Wawasee (and apparently Walnut Lake), but unlike Lake Nipigon, where neither of these species was taken, Lake Pepin, where only a single specimen of *Corethra* was found, and also unlike Lake George, Green Lake in Wisconsin, the Finger Lakes of New York and Lake Okoboji.

The two oligochaetes, *Limnodrilus hoffmeisteri* and *L. clapedianus* occur in both Douglas and Third Sister Lakes and here again it is interesting to note that markedly polluted reaches of the Illinois River are the only other local-

ities, of those here mentioned, from which these two species have been reported. It is true that specific determinations of the oligochaetes have not usually been obtained, and possible that if they had been, there would be more records of these two species in unpolluted waters of American lakes.

In general terms, the profundal benthic faunas of Douglas and of Third Sister Lakes are comparable with those in many European lakes. This is especially true of the "*plumosus-Corethra* type" common among the lakes of Northern Germany. The bottom faunas of certain Swiss lakes, for example St. Moritz and Le Leman, are quite unlike those found in any lake studied in this investigation.

Since the bottom fauna of the littoral and sublittoral zones did not come within the scope of the major problem considered in this paper, but was only considered incidentally when representatives were taken in bottom samples, no attempt will be made to compare this fauna in Douglas and Third Sister Lakes with that in other lakes. It may, however, be mentioned in passing that, so far as is known, the shallower water benthic fauna in the lakes studied by the writer has many points of similarity with that in Lake Mendota, Lake Wawasee and Oneida Lake.

SEASONAL VARIATION AND DEPTH DISTRIBUTION

VARIATIONS

The bottom fauna within the profundal zone, in the lakes studied, has shown clearly defined seasonal variations. Such changes have been of two sorts: (1) variations in species present, and (2) fluctuations in total numbers of the population. These phenomena will accordingly be considered under two headings, qualitative and quantitative.

Qualitative Seasonal Variations

One phase of the writer's investigations has been a study of any possible qualitative variations of bottom fauna within the true profundal zone. Physical-chemical determinations soon demonstrated that there were relatively large areas both on the bottom of Third Sister Lake and within the major depressions in Douglas Lake which constituted typical profundal habitats. In order, however, to have a region for study where the environmental conditions of the benthic habitat were at the maximum of their intensities, the area beneath the deepest water in both lakes was selected. Therefore, the collection of samples for this phase of the problem was restricted to the area within the 18 m. contour in Third Sister Lake, and the 21 m. contour in Douglas Lake for all depressions except Stony Point, where the 17 m. one was chosen.

Between October 20, 1926 and February 9, 1929, 163 samples were taken from below the 18 m. contour in Third Sister Lake. Table XX presents a summary of these data. It will be seen that each spring (in April) and each

fall (late in November or early in December) the area below 18 m. was invaded by organisms other than those which inhabited that region during the rest of the year. Such invasions are shown in the table in the next to the last column. Shortly after November 24, 1926, a layer of ice formed over the lake too thin to support a man's weight and yet thick enough to prevent the use of a boat. Hence no bottom samples were taken again until January 5, 1927, and as a result the appearance of the invaders was missed that fall. That such transitory bottom species occurred below 18 m. sometime in December of that year seems certain when it is pointed out that on November 24 there was a population of 23 animals per sq. m., in addition to the typical profundal species on the bottom between 16 and 17., (Table XXI). These bottom species which periodically invade the deepest water of this lake in the spring and fall are usually water mites, ostracods and, on rare occasions, specimens of *Hydromermis*.

Even within the typical profundal fauna there is a seasonal qualitative variation. A glance at the data in Table XX will show that *Protenthes* is by no means a constant inhabitant of the deeper zone and even the *Chironomus* larvae disappear at times. Thus it often happens that in the late fall the list of benthic inhabitants beneath the deepest water is reduced to two namely; *Corethra* larvae and the tubificids. At no time was a sample taken from this region of Third Sister Lake, however, when either of these two types was absent.

In Douglas Lake, practically all samples were taken during the months of June, July, and August. One result of this fact is an apparent absence of pronounced qualitative seasonal variation in the profundal zone. However, in view of the repeated autumnal and vernal qualitative changes in the bottom fauna within the profundal zone of Third Sister Lake, a special trip to Douglas Lake in late October seemed advisable in order to determine whether or not a similar change took place there. Accordingly, Douglas Lake was visited October 19-21, 1928, and data on the bottom fauna in South Fish-Tail and Roberts Point depressions were secured. The last line of Table XIV shows that a qualitative change had begun to appear beneath the deepest water in South Fish-Tail depression. Although only typical profundal species were as yet present in the deepest water a distinct change was evident within this group. The quantitative change was most striking, but it may also be pointed out that *Protenthes* larvae which had been absent from July 30 to August 12 were then present in appreciable numbers. The data for Roberts Point depression are, however, more convincing. In this depression there could be no doubt of the qualitative changes. A few ostracods were taken along with the typical profundal animals at 22 m. on August 6, and August 10, the number of ostracods had decreased slightly but a few *Johannsenomyia* larvae were present. In the samples of October 20 there were found ostracods, hydrachnids, larvae of *Sialis infumata* and a few *Dorylaimus*.

A summary of all bottom samples within the deeper profundal zone in Douglas Lake is given in Tables XIV-XIX. These data are arranged according to depressions and show the results for the summers of 1923, 1926, 1927 and 1928. Examination of these tables demonstrates that the qualitative variation within the typical profundal fauna, which was evident in Third Sister Lake, also occurs in Douglas Lake. There are certain differences, however. In Douglas Lake not only do *Chironomus* and *Protenthes* disappear entirely beneath the deepest water at certain times but the tubificids also are frequently absent. This means that at times nothing but *Corethra* larvae or pupae are to be found in the mud at these depths. And although *Corethra* larvae never entirely disappeared in any depression of Douglas Lake, there were many occasions when they were almost completely absent.

Depression individuality in terms of qualitative differences of the bottom fauna is most clearly shown when the data for the depressions are arranged in two groups. In the larger group are South Fish-Tail, Fairy Island, Sedge Point and Roberts Point depressions. This group is typified by an almost complete absence of anything except *Corethra*, *Chironomus*, *Protenthes*, and *Tubificidae* from the deeper profundal zone during the summer months. The smaller group includes Stony Point and Grapevine Point depressions where the bottom fauna typically included several other species.

It will be seen that in Tables XVIII and XIX the column headed "All Others" contains records of a miscellaneous bottom population which occurred beneath the deepest water in Stony Point and Grapevine Point depressions. In the latter, the types most frequently found, in addition to the four given in the tables, were, *Hydromermis*, *Dorylaimus*, and *Pisidium*. In Stony Point depression, the list is considerably longer. In the "All Others" column of the table for that depression are included records for *Hydromermis*, *Dorylaimus*, *Musculium*, *Pisidium*, *Amnicola*, *Campeloma*, *Valvata*, and *Ostracoda*. Although *Sphaeriidae* occurred within the profundal zone in Douglas Lake, they were seldom taken below 21 m., and then only specimens of *Pisidium compressum* could be expected.

Quantitative Seasonal Variations

A clearer idea of the magnitude of quantitative faunal variations within the deeper profundal zone is to be had by a glance at Fig. 12, where number of organisms per sq. m. below the 18 m. contour in Third Sister Lake is shown graphically. The curves are plotted on a scale based on a numerical progression. This scheme was resorted to in order to allow plotting curves for all the organisms on one graph. It will be realized that the effect of this is to somewhat reduce the peaks of the lower curves and enormously reduce the *Corethra* and "totals" curves in proportion to the others.

In general, the most uniform in point of numbers present are the tubificids. If the more or less ephemeral, miscellaneous group, called "all others,"

THIRD SISTER LAKE

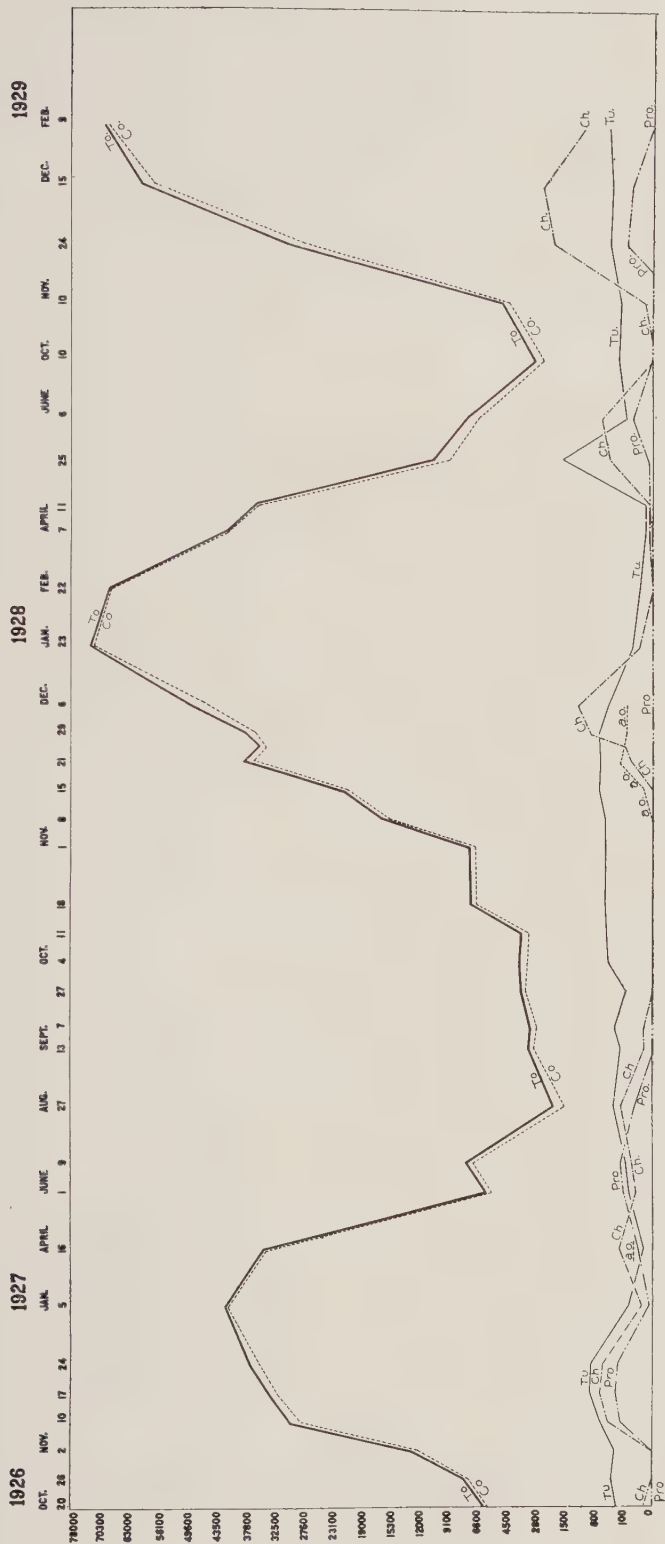


FIG. 12. Quantitative seasonal variation of profundal bottom fauna within the 18 m. contour, Third Sister Lake. The curves indicate number of individuals per square meter of total benthic fauna (To), Corethra larvae and pupae (Co), Chironomus larvae (Ch), Protenthes larvae (Pro), Tubificidae (Tu), and all others (a.o.).

(a. o. in the figure) is omitted from consideration, the lower curves all show a general similarity. Chironomus varied from complete absence on various dates to a maximum of 2400 per sq. m., on December 15, 1928. Protenthes larvae were absent for months at a time and their maximum (November 17, 1926) was only 200 per sq. m. The tubificids varied from a minimum of 23 to a maximum of 1550 per sq. m. of bottom. This maximum figure was obtained by the combination, and consequent averaging, of all samples from the 16, 17, and 18 m. depths on April 25, 1928. Studies on the depth distribution of these animals, as will be shown later, make it obvious that this accounts for the sudden increase in numbers shown in the curve. Thus at 18 m. on April 7, there were 23 tubificids per sq. m., on April 11 there were still 23, then, by the method mentioned above, the number jumped to 1550 on April 25 but had fallen off again on June 6 to 90 per sq. m. Quite evidently, the figure of 1550 for April 25 is very much too high for the 18 m. zone, although it does state the fact for the whole area of bottom below 16 m. If this false maximum be omitted, then the quantitative variation of the tubificids was from 23 to 734 per sq. m. The population of the miscellaneous group, "all others," reached a maximum of slightly more than 100 on November 21, 1927, and, on several other occasions, approached 90 individuals per sq. m. These animals are present within the profundal zone, as was pointed out before, only in the spring and autumn.

The curves for "Corethra" and the "total" attract attention in the figure. A glance is sufficient to show that the "total" curve is, in all its aspects, little more than a reflection of the Corethra curve. Corethra larvae dominate, numerically, the life of the profundal benthic habitat in Third Sister Lake in a striking way. During this investigation their numbers have never fallen below 1500 per sq. m. of bottom surface within the 18 m. contour, and they have reached a maximum of over 71,500 sq. m. The maximum found in Lake Mendota (Juday, 1922) of 33,800 per sq. m. seemed large indeed but the number in Third Sister Lake, per unit area, is more than double that figure.

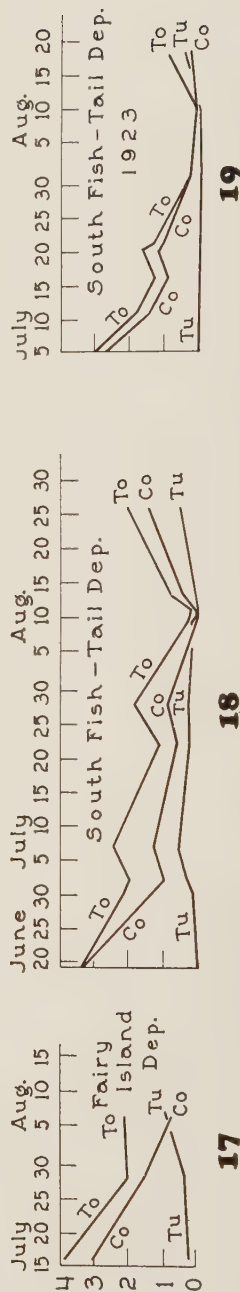
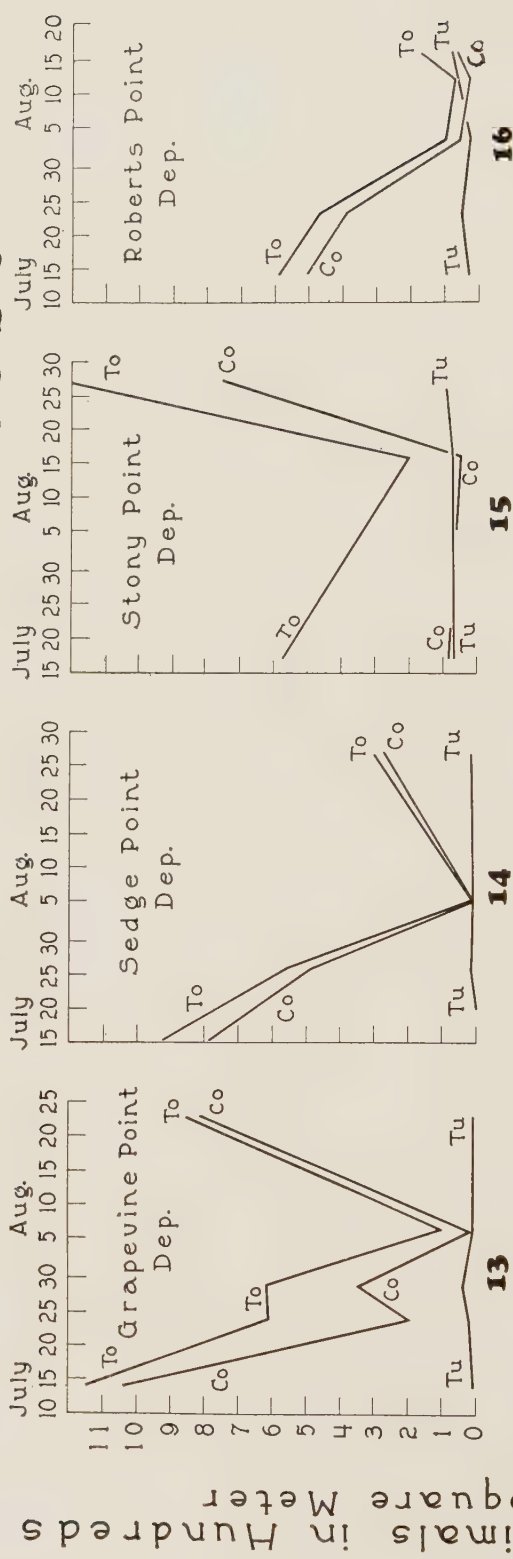
The fluctuations of total profundal bottom population in the deepest region of Third Sister Lake showed a clearly defined periodicity. In late summer and early autumn, there was an annual minimum followed later in the fall by a very sudden and considerable increase in all species. This increase continued, so far as total population was concerned, until midwinter, when the annual maximum was attained. During the winters of 1926-7, 1927-8, and 1928-9, this maximum occurred in January and February. During March in each of these years, ice conditions were such as to prevent work on the lake but by early April, when the first spring observations were made, the benthic population in the center of the lake had materially declined. The decrease in numbers continued slowly throughout the spring and summer until the minimum was again reached in late August or early September.

The increase in autumn was not entirely simultaneous for all organisms concerned but was first evident in the *Corethra* larvae. This was followed by an augmentation of the population among the other bottom animals. That the autumnal increase is a sudden and pronounced one each year is attested by the data. Thus on October 26, 1926, the total population of the profundal bottom within the 18 m. contour was slightly more than 7,700 per sq. m. One week later the total per sq. m. of bottom within the same contour was a little more than 12,800, and again 8 days later the figure was approximately 29,700. In the autumn of 1927, the onset of the change was about one week later and the increase in total number of animals per sq. m. was as follows: November 1, 7,360; November 8, 16,200; November 15, 21,700; November 21, 37,700. Again in 1928, a similar change took place between November 10 and 24 with an increase from 4,900 on the former date to 30,600 on the latter or an increase of 25,700 individuals per sq. m. in 14 days.

It is true, as has been pointed out before, that these fluctuations of total number of animals per unit area in the deeper profundal is very largely determined by changes in numbers of *Corethra* larvae. However, the autumnal increase is often just as abrupt in the case of other types, although not of such a magnitude. An instance of this kind is shown by the data for November 2 and 10, 1926. On the first date, the bottom population per sq. m. was found to consist of 12,665 *Corethra* larvae, and 171 tubificids. Eight days later, on November 10, the population per sq. m. had increased to 28,800 *Corethra* larvae, 423 tubificids, 311 *Chironomus* larvae and 156 *Protenches* larvae. Thus the *Corethra* had slightly more than doubled, the tubificids had nearly trebled their numbers while *Chironomus* had increased from 0 to 311 and *Protenches* from 0 to 156.

Since sampling in Douglas Lake was confined to summer months, only a part of the seasonal cycle is adequately understood. The facts so far as they are known for that lake, agree in general trend of events, however, with those for Third Sister Lake. Quantitative data on seasonal variations of bottom fauna in Douglas Lake have been arranged according to depressions, and graphs prepared (Figs. 13-31) showing the seasonal variations in number per sq. m. within the 21 m. contour in all depressions except Stony Point depression where the curves are based on the number of organisms per sq. m. below 17 m. In each graph three curves have been drawn, one showing numbers of tubificids, a second indicating the abundance of *Corethra* larvae, and a third representing the total population per sq. m. In one figure (22), the curve for *Chironomus* has been added. The data for the three curves (tubificids, *Corethra*, and totals) have been selected since it was felt that these gave an adequate and lucid representation of quantitative changes going on within the deeper profundal zone.

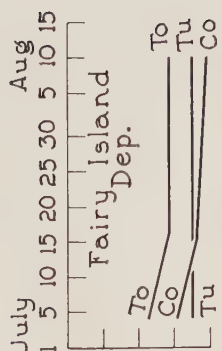
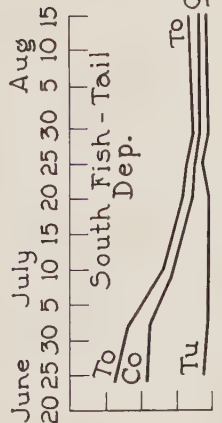
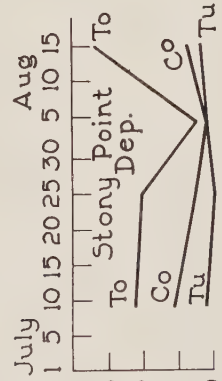
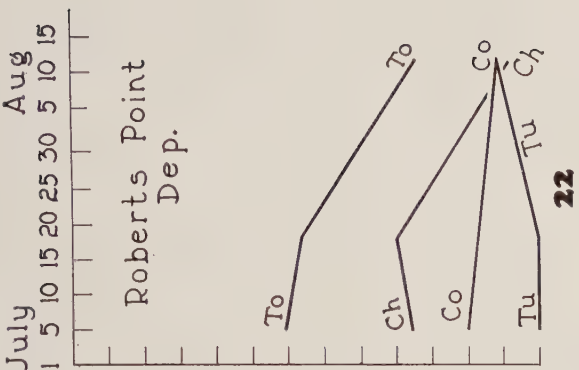
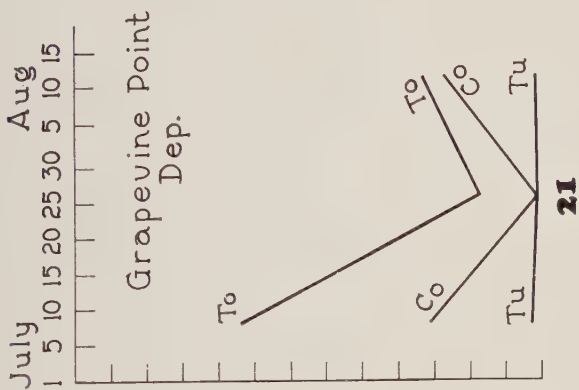
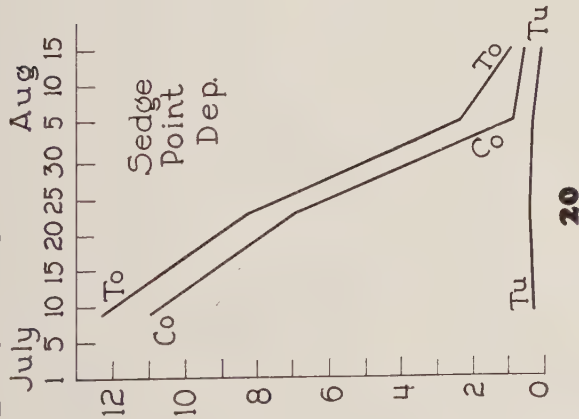
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FIGS. 13-19. Quantitative seasonal variations of profundal bottom fauna within the deeper profundal zone, Douglas Lake, in 1926. The curves indicate total benthic fauna (To), Corethra larvae and pupae (Co), and Tubificidae (Tu) in number of individuals per square meter of lake bottom on the dates shown at the top of each figure.

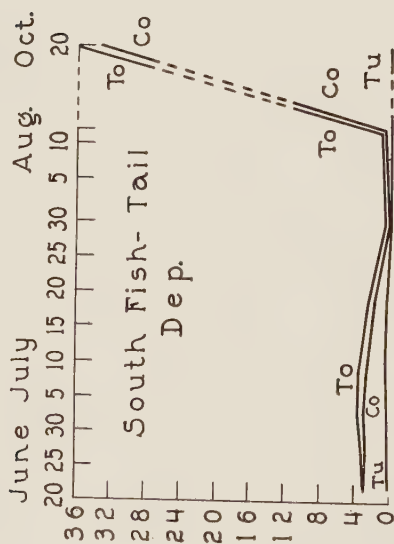
DOUGLAS LAKE - 1927

Bottom Animals in Hundreds per Square Meter.

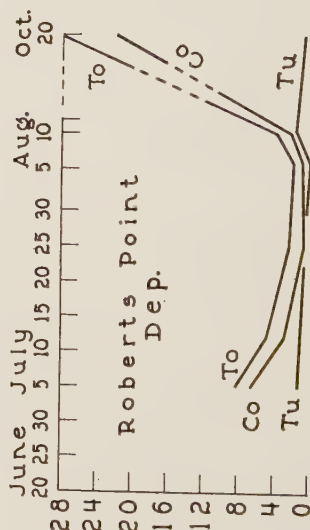


Figs. 20-25. Quantitative seasonal variations of profundal bottom fauna within the deeper profundal zone, Douglas Lake in 1927. The curves indicate total benthic fauna (To), Corethra larvae and pupae (Co), and Tubificidae (Tu) in number of individuals per square meter of lake bottom on the dates shown at the top of each figure.

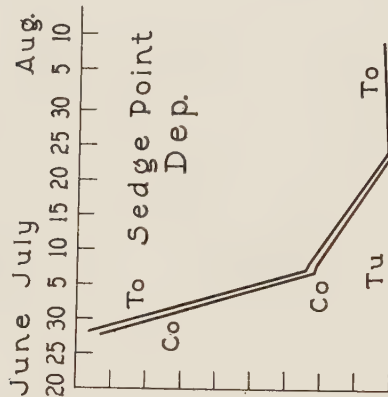
DOUGLAS LAKE - 1928



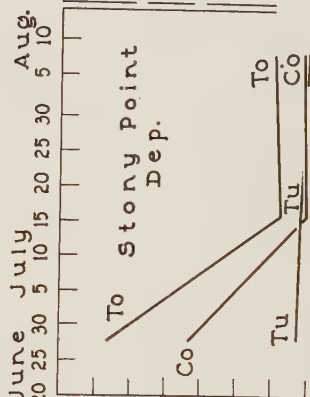
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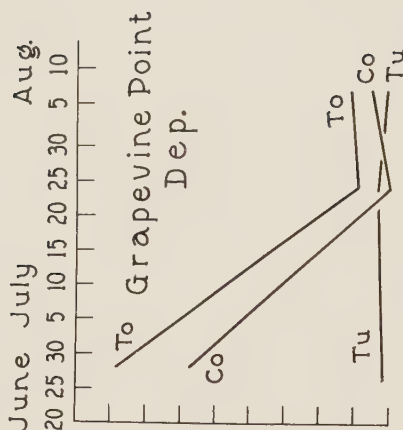
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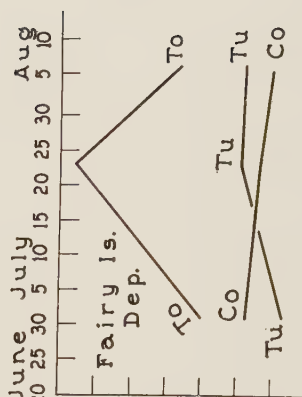
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28



31

Bottom Animals in Hundreds
Per Square Meter

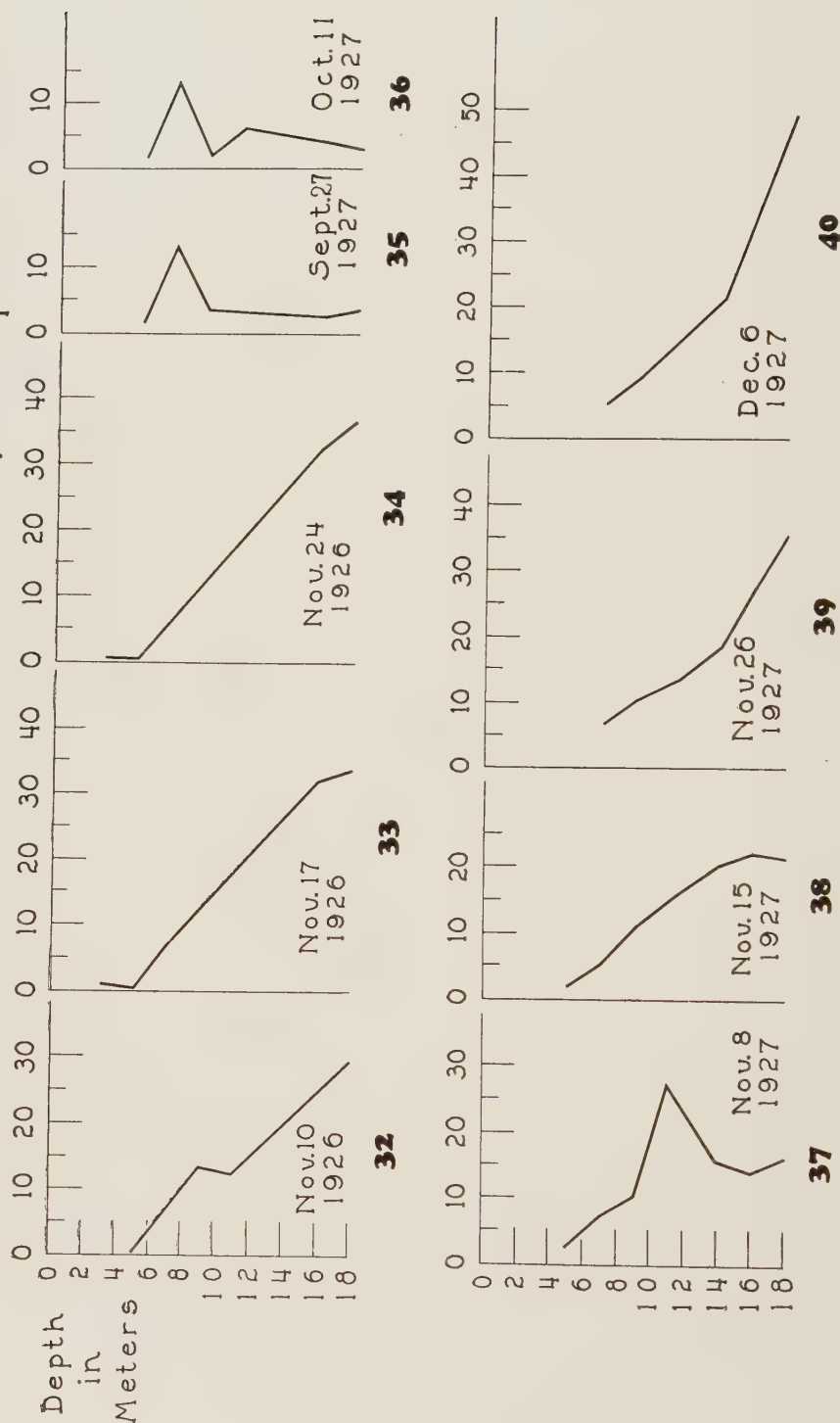
FIGS. 26-31. Quantitative seasonal variations of profundal bottom fauna within the deeper profundal zone, Douglas Lake in 1928. These curves indicate total benthic fauna (To), Corethra larvae and pupae (Co), and Tubificidae (Tu) in number of individuals per square meter of lake bottom on the dates shown at the top of each figure.

One general tendency of quantitative variations in the profundal bottom fauna was common to all depressions, namely, the gradual decline in numbers from the time the first samples were taken, usually in late June, until a summer minimum was reached some time between July 25 and August 15, depending on season and depression. There was also a nearly uniform tendency for the population to show a slow but steady increase from this time until the last samples of the season were taken. Comparison of the curves will make these facts evident. In this respect, each depression of Douglas Lake follows the same cycle as is shown by the single one in Third Sister Lake.

Season after season it became increasingly evident that each region of deep water in Douglas Lake had a certain individuality in terms of its profundal benthic fauna. The nature of this individuality is dual; partly quantitative, partly qualitative. Thus if it became necessary to have considerable numbers of any particular typical profundal form for experimental, rearing, or other purposes, the author could, with some confidence, go to a particular depression in search of the animal needed. If *Corethra* larvae were wanted early in the season, Sedge Point depression could usually be depended upon to yield the largest crop per unit area. A little later in the season it would be useless to visit Sedge Point depression in search of that particular animal, and tubificids were never there in large numbers. When tubificids were sought, Fairy Island depression could be expected to furnish a dependable, though never an extraordinarily numerous, supply. Grapevine Point and Roberts Point depressions were found to be perhaps the most dependable regions in terms of general productivity of typical profundal animals. In point of diversity of deep water benthic fauna, Stony Point depression soon came to be known as the most productive region. This depression also made the most sudden and pronounced recovery from the mid-summer minimum of late July and early August. Fairy Island depression, although the most dependable in production of *Tubificidae*, was, on the other hand, uniformly the least productive in point of total benthic population per unit area.

Consideration of data presented in the curves (Figs. 13-31) will make clear certain further aspects of seasonal variations within the various depressions. It will be evident, for example, that no generalization as to the exact date on which the annual minimum will occur can be made on the basis of the data now available. Perhaps it is safe to assume that the individuality of the seasons, a matter which will receive further consideration later, is greater in this respect than is the individuality of the depressions. Certainly, the records for the season of 1927 seem to point in that direction. One further tendency, of a somewhat minor nature, is clear, namely, the repeated decrease, year after year and in most depressions, of the numbers of *Corethra* larvae below the average per unit area for the tubificids. Finally, the very considerably lower summer totals in Douglas Lake, considering the whole

Bottom Animals in Thousands per Square Meter



FIGS. 32-40. Depth distribution and zonation of bottom fauna in Third Sister Lake, in 1926 and 1927. The curves show the number of individuals of the total benthic fauna in thousands per square meter of lake bottom at the depths indicated (0-18 meters).

season and the whole profundal region of the lake, when compared with similar data for Third Sister Lake, are at once apparent.

The results obtained during the short study of the benthic fauna in October, 1928, are very interesting from several aspects. The relatively very considerable increase in bottom population shown graphically in the 1928 curves for South Fish-Tail and Roberts Point depressions (Figs. 26 and 29), offer rather convincing evidence that, just as in Third Sister Lake, the number of individuals per unit area within the profundal zone of Douglas Lake is suddenly and materially augmented in the fall of the year. In Douglas Lake the change appears to come approximately one month earlier than in Third Sister Lake. This may very possibly be due to a combination of two factors, the difference in latitude (represented in 300 miles) of the lakes and the perhaps still more significant difference in their size.

DISTRIBUTION

Sampling series, previously mentioned, were taken in an attempt to determine the depth distribution of the profundal fauna. Certain features at once became apparent which rendered it desirable to know whether or not there was any seasonal cycle in the character of this distribution. With this object in view, sampling series were run each summer, in various regions of Douglas Lake and at selected intervals between November, 1926 and February, 1929 in Third Sister Lake. In addition to these, a few series were taken in other lakes for purposes of comparison.

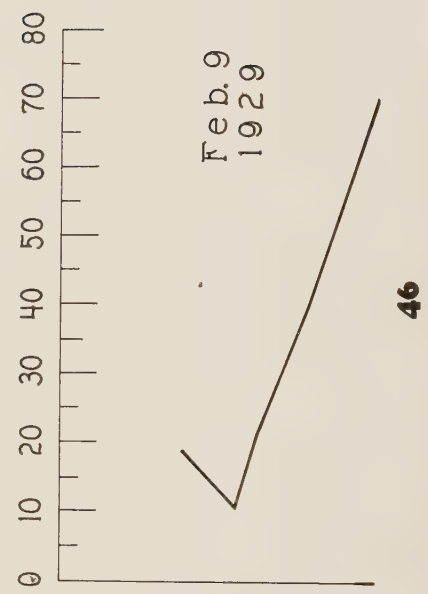
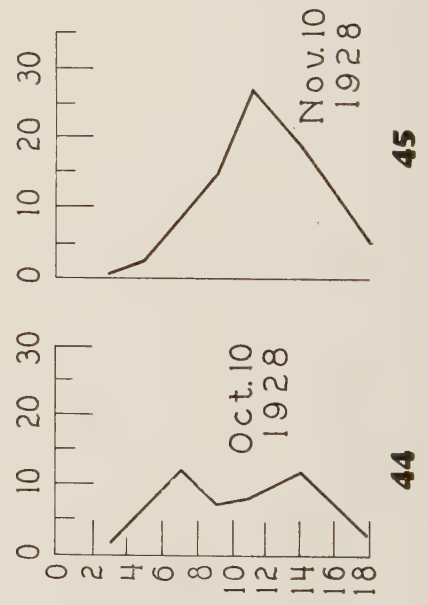
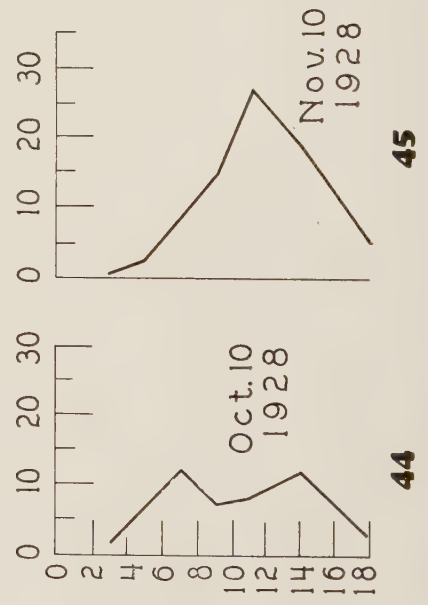
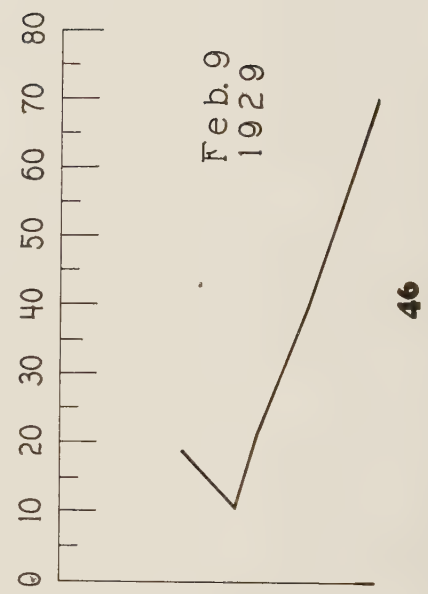
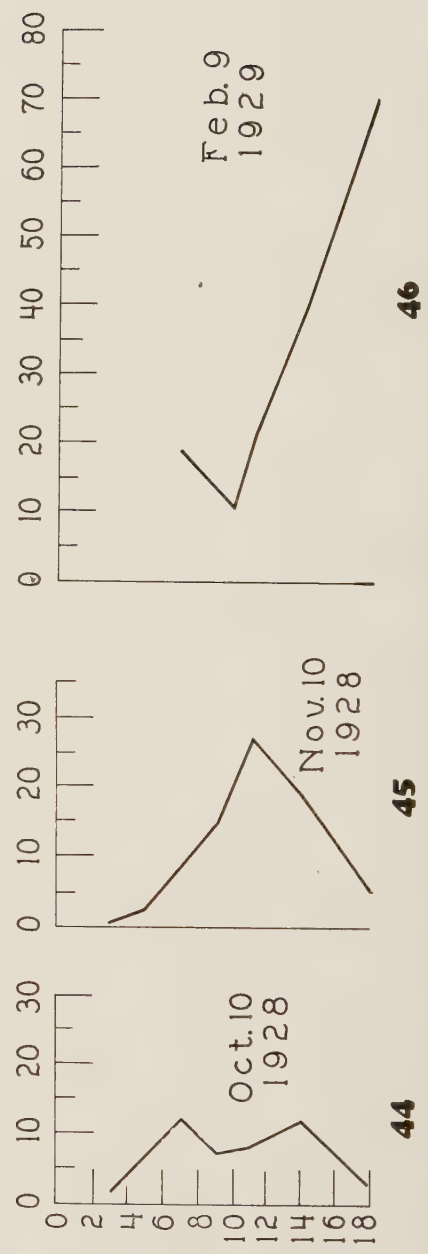
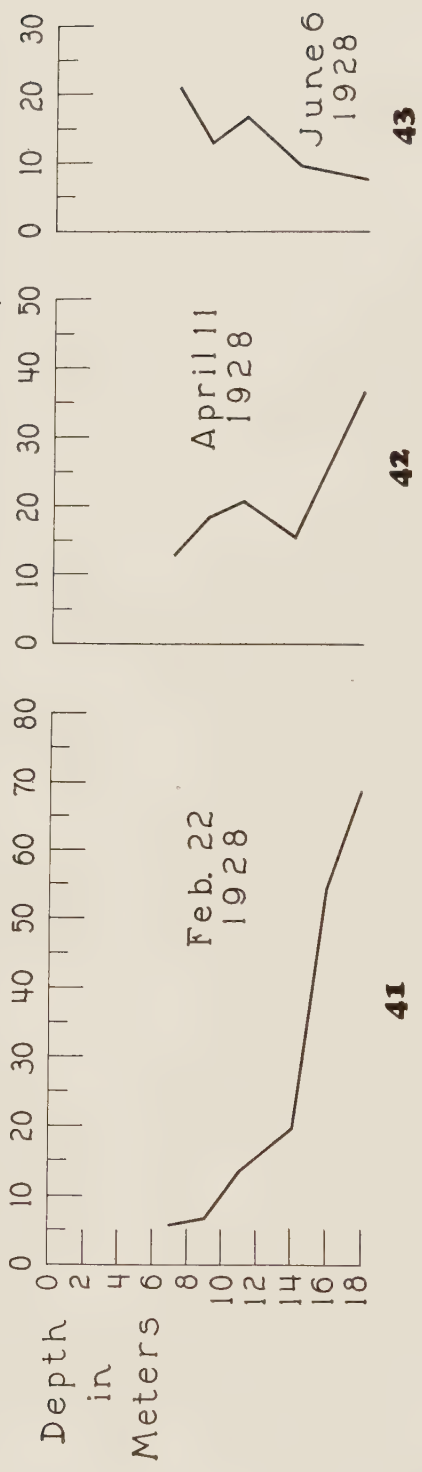
Zonation

In Third Sister Lake, the first sampling series for determining depth distribution of the benthic fauna, taken on November 10, 1926, began at the 18 m. depth and extended up the slope to the 5 m. depth. From among the subsequent series 14 have been selected and graphs prepared from the data (Figs. 32-46). The curves represent distribution, according to depth, of the total benthic fauna in terms of organisms per sq. m.

As was expected, the distribution was not uniform from deep to shallow water. During part of the year, the general trend was toward decrease of numbers with decrease of depth. At other seasons, the ratio between depth and total population per unit area of bottom was the reverse. On November 10, 1926 (Fig. 32) the number of organisms steadily decreased between 18 and 11 m.; increased between 11 and 9 m.; and again decreased sharply to 5 m. where the population was very small. At 9 m., as the curve shows plainly, there was a distinct zone in which the individuals of the benthic fauna were considerably more numerous than immediately above or below. This feature of the depth distribution, which repeatedly occurred at certain seasons of the year, will be referred to hereafter as the concentration zone.

One week after the first sampling series had been taken, another was ob-

Bottom Animals in Thousands per Square Meter



FIGS. 41-46. Depth distribution and zonation of bottom fauna in Third Sister Lake, in 1928 and in February 1929. The curves show number of individuals of the total benthic fauna in thousands per square meter of lake bottom at the depths indicated (0-18 meters).

tained which extended from 18 to 3 m. The curve (Fig. 33) shows a nearly uniform decrease in numbers from 18 to 5 m. The previous sharp zonation had disappeared and only a slight indication of it was evident at 16 m. It will be noticed from the curve that the total population per unit area remained small from 5 to 3 m., a feature of depth distribution always found in Third Sister Lake whenever the sampling series were continued to the edge of the littoral zone. One other feature of the two curves (Figs. 32-33) is worthy of note; viz., the noticeable increase in number of organisms per sq. m. in the deeper profundal. This throws an interesting light on that sudden increase in numbers within the deepest profundal discussed in the section relating to quantitative variations. It appears that the sudden augmentation beneath the deepest water is, at least partly, brought about by obliteration of the concentration zone and a dispersal of its large population over the lake floor within the deepest regions.

The third series selected was secured on November 24, 1926. Conditions of the previous week were little changed. The curve (Fig. 34) is almost identical in general form with the preceding one except for two minor differences. It shows a still further increase in individuals within the deepest profundal zone and it is more nearly a straight line from 18 to 5 m., having lost some of the convexity, toward the right, which showed in the earlier curve. This last fact indicates a more nearly complete obliteration of the concentration zone.

Beginning with data for September 27, 1927, 12 curves (Figs. 35-46) have been prepared which depict graphically the annual cycle of events for depth distribution of the Third Sister Lake benthic fauna. On the first four dates, sampling series extended from 18 to 5 m. The series were not extended further into shallow water since previous experience had shown that few profundal bottom animals might be expected there. The next 5 series extended from 18 to 7 m.; the next 2 from 18 to 3 m.; and the last one began at 18 m. and ended at 7 m.

On September 27 (Fig. 35), the number of benthic animals at 18 m. was somewhat more than 3600 per sq. m. A slight decrease occurred between 18 and 16 m., followed by a steady but very slow increase up to 9 m. Between 9 and 7 m., there was a sudden and considerable increase from a little more than 3700 at the greater depth to almost 13,500 at the lesser. The benthic population then decreased again very rapidly to about 1400 per sq. m. at 5 m. The distribution was characteristic of the late summer and early fall conditions and the pronounced concentration zone with its maximum at 7 m. and extending from 5 to 9 m. was a thoroughly typical one.

Two weeks later, October 11, the population at 18 m. was almost exactly that of the previous date but there was a steady increase up to 11 m., followed by a sharp decrease to the 9 m. depth, and this again by another and more pronounced increase to the maximum at 7 m. As before, the popula-

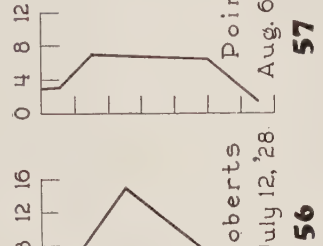
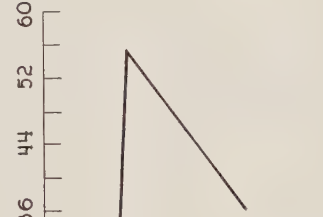
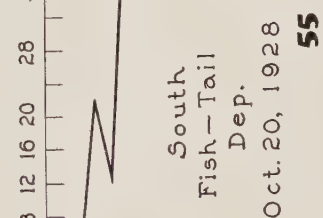
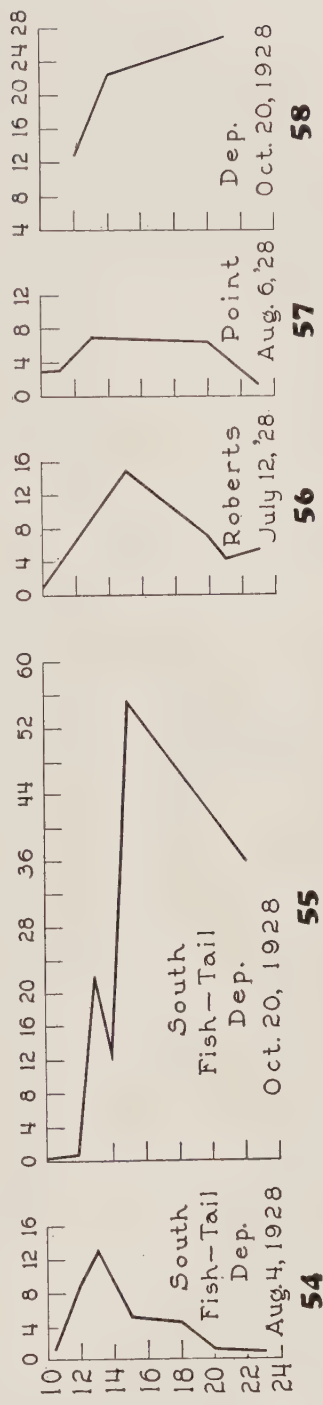
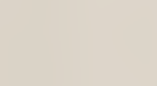
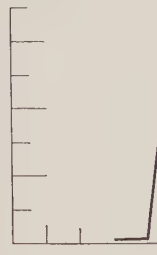
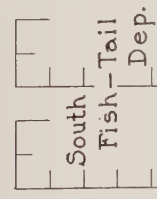
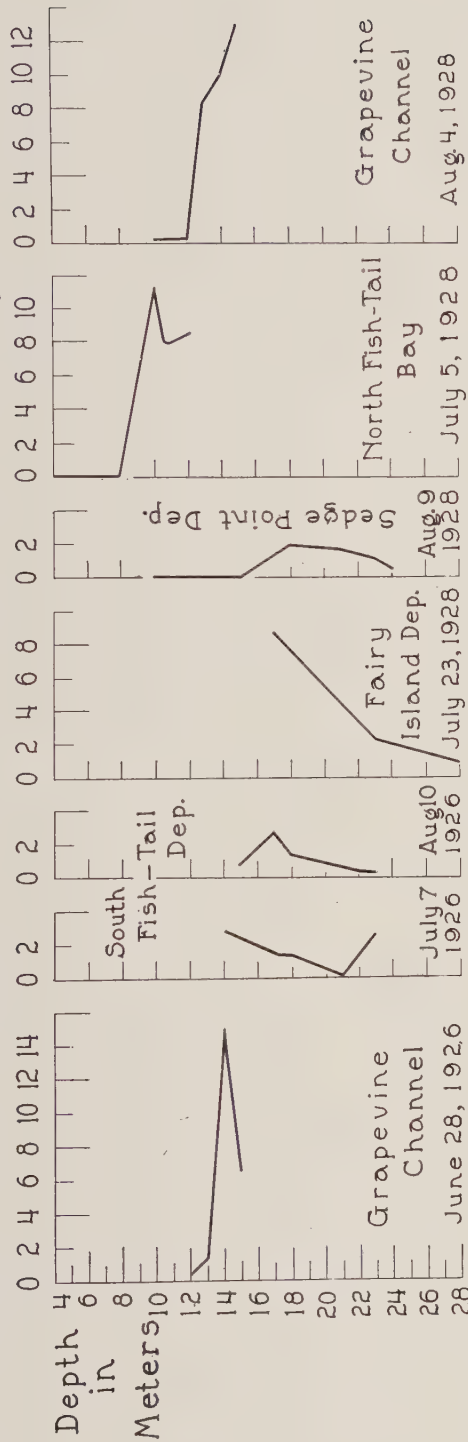
tion decreased rapidly between 7 and 5 m. to a minimum at the latter depth. The curve for this date (Fig. 36), shows the same typical concentration zone at 7 m. but with an accessory one slightly developed at 11 m. Figure 37 gives data for November 8. On that date, the two concentration zones had merged into one which was much broader and of considerably greater magnitude with its maximum at 11.5 m. The mass of the benthic fauna within the profundal zone was not only increasing, but the concentration zone was shifting into deeper water and spreading out. The deeper profundal had begun to be affected by the autumnal change and its benthic population had suddenly increased to over 16,000 per sq. m.

A still more pronounced change occurred within the next week, as shown by the curve for November 15 (Fig. 38). When bottom samples were taken on that date, the concentration zone was no longer in evidence, but rather a steady decrease with decrease in depth, was found, except from 18 to 16 m. The sharp peak of the curve for the week before had disappeared and the curve now showed a gentle convexity to the right. In contrast to this condition, the next curve (Fig. 39), giving the data for November 26, shows a slight concavity on the right. The population at 18 m. on that date was still larger. There occurred a continuous, although not quite uniform, decrease as samples were taken at successively shallower depths up to the final sample at 7 m.

On December 6, a still further increase was noted at 18 m. and, as before, the decrease in population with decrease in depth was continuous (Fig. 40). On February 22, typical midwinter conditions prevailed and the annual maximum occurred at 18 m. A sharp decline in population was found up to 14 m. and thence to 7 m. the decrease was less abrupt, although uninterrupted (Fig. 41). If the curves for November 26, December 6 and February 22 be compared, it will be seen that the concavity toward the right steadily increased and that the population below 14 m. was continuously growing. In effect, this had, by the last date, produced a concentration zone extending from 14 to 18 m. with its maximum at the lower depth.

Early spring conditions are revealed by Fig. 42, which is the curve for April 11. The maximum was still at 18 m. where the benthic population was more than 36,500 per unit area. However, a return to summer conditions with a concentration zone in shallower water was evidently on the way. The curve shows plainly the beginnings of such a movement, with the incipient concentration between 14 and 7 m. and its maximum at 11.5 m. The curve for June 6 (Fig. 43), offers further evidence that the April data were collected just at the time when the summer concentration zone was beginning to form. Unfortunately, the June 6 series was not extended farther up the slope than the 7 m. depth. A clearly defined concentration zone was present between 14 and 9 m. and the maximum was, as usual, at 11.5 m. The peak found at 7 m. shows the presence of another concentration zone above the

Bottom Animals in Hundreds per Square Meter



FIGS. 47-58. Depth distribution and zonation of bottom fauna in Douglas Lake. The curves show number of individuals of the total benthic fauna in hundreds per square meter of lake bottom at the depths indicated (0-28 meters).

9 m. level, probably with its high point where the series was discontinued. If Fig. 36 is compared with Fig. 43, it will be seen that from 18 to 7 m. the curves are much alike, except that the magnitude of the population represented by the former is much less than that in the June curve. If the similarity of these curves is considered in conjunction with the data from bottom samples taken at various depths, but not in series, during the springs of 1927 and 1928, then it seems almost certain that had the series of June 6, 1928 been continued to 3 m., the curve would have declined sharply from the 7 m. maximum to a very low total at 5 m. and continued low to 3 m.

In the fall and early winter, 1928, the cycle of events which had taken place in the depth distribution of the bottom animals during the two preceding autumns was repeated. Curves prepared from the data for 3 dates (Figs. 44-46) show: (1) the inception of the autumnal shifting in the concentration zone; (2) the merging of the intermediate, double concentration zone into a broad and sinking single one; and (3) the fully established midwinter concentration in deep water.

The curves for October 10 and November 10, 1928 are comparable with those of October 11 and November 8, 1927. Perhaps the two for the fall of 1928 may represent intermediate stages between the two for 1927. Other such interpolations of curves might be made, and postulates drawn as to detailed changes in the annual cycle of the concentration zone. It must be remembered, however, that this would be largely a matter of conjecture, and furthermore that the transition from one phase to another is not exactly duplicated as to detail in each succeeding year.

The restriction of the sampling almost entirely to the summer months in Douglas Lake, together with the limitations placed on intensive study of any one depression by the necessity of a single investigator spreading his efforts over what amounts, in effect, to 6 lakes within one, have resulted in a much less complete series of curves than was obtained for Third Sister Lake.

Figures 52 and 54 illustrate depth distribution of total bottom population per unit area in North and in South Fish-Tail Bays respectively. A feature of the depth distribution, which occurs repeatedly in Douglas Lake particularly during the first half of the summer, is shown in the curves of Figs. 48, 52 and 56. This feature is the development of a pronounced concentration zone, usually within the lower sublittoral, followed by a sharp decline in population beginning just above the upper limit of the hypolimnion, and another slight increase as the deepest region is approached. That a concentration zone is present in various regions of Douglas Lake, although at a greater depth than in Third Sister, is demonstrated by the figures in general and particularly well by Figs. 47, 49, 54, 55 and 56. The curve for Roberts Point depression on July 12, 1928 (Fig. 56), is typical of the depth distribution which is probably most frequently found in the major depressions of Douglas Lake during June and July. That the truncated form of the curve

for August 6 of the same year, and in the same depression is not due entirely to absence of data for depths between 13 and 20 m. on that date, seems to be indicated by bottom fauna counts between those depths on comparable dates in that and other years. Bottom samples taken at random between these 2 depths seldom yielded as high a count during August as during July.

Sedge Point depression usually showed a different sort of depth distribution than was typical in the other major regions of deep water. The curve for August 9, 1928, illustrates this difference, although it should be pointed out that, occasionally, earlier in the summer, slight indications of a concentration zone were found even in Sedge Point depression. No complete sampling series, extending from deep to shallow water, was taken in Fairy Island depression during any one day. Figure 50, however shows the results of a partial series which extended between 28 and 17 m. Since the population almost certainly decreased rapidly between 15 and 10 m., it may be regarded as probable that a well developed concentration zone occurred between the depths of 20 and 10 m. This is further substantiated by results of sampling done at other times in the sublittoral zone on the edge of, or adjacent to, the Fairy Island depression. In Grapevine Channel, there was usually a well developed concentration zone with a region of lower productivity below. However, as on August 4, 1928 (Fig. 53), this was not always the case, and, on several occasions, the population decreased sharply and nearly uniformly from the deepest water to a depth of about 12 m., above which few bottom animals were ordinarily found.

Some indication of the autumnal depth distribution of the Douglas Lake bottom fauna is given by the two curves for October 20, 1928 (Figs. 55 and 58). The curve for Roberts Point depression is based on data from three depths only and consequently may not reveal the whole story of distribution on that date. It may be pointed out, however, that if the distribution was of the sort to be expected (judged by what is known for both Douglas and Third Sister Lakes), then data for those depths at which samples were actually taken would yield a curve like the one obtained, even if such data were selected from a very complete series instead of from an incomplete one. The curve for the sampling series of the same date, but taken in South Fish-Tail depression and extended on into Grapevine Channel, is much more dependable, since the data are more complete. There, the distribution was much the same as that found in Third Sister Lake during the autumnal obliteration of the concentration zone and the dispersal of its numbers over the bottom in the deeper water.

Seasonal Distribution

The graphs prepared to show zonation indicate only total number of organisms per sq. m. The seasonal and qualitative aspects of depth distribution, which may be considered together, require more detailed presentation of

the data. Therefore, a series of tables has been prepared, in which the qualitative and the seasonal aspects have been accentuated. Tables XX-XXVII present the data primarily from the seasonal aspect for different depths in Third Sister Lake. In Table XXVIII the data are arranged to show, more clearly, the qualitative phase of seasonal and depth distribution of bottom animals.

Not only does the total number of benthic organisms per unit area vary with depth and with the season but each species included in the total has distinctly individual variations of the same two sorts. Thus, *Corethra* larvae were found to vary in the following ways: (1) the total number in the whole lake varied with the season, (2) the number per unit area of bottom varied, (a) with the season differently at each different depth (Tables XX-XXVII) and (b) with the depth differently at different seasons of the year (Table XXVIII). Computations of the standing crop at various seasons, which have not been included herein but may be made with the data given, show statement (1) in the preceding sentence to be a fact. The columns for *Corethra* in Tables XXI, XXV, and XXVI will illustrate what is meant by (2, a) above. In the same way, (2b) above will be evident if the data for June 6, 1928, November 10, 1928, and February 9, 1929 (Table XXVIII), are compared. A further factor affecting the numerical variations of *Corethra* larvae at different seasons and depths is the occurrence of considerable numbers of these larvae in the limnetic habitat.

What has been pointed out for *Corethra* could be repeated for each of the other types of bottom animals. *Chironomus* larvae vary greatly with the depth at practically all seasons, although the variation was more abrupt at certain times. When considered alone, they also show a pronounced concentration zone, as for example, on October 11, 1927 (Table XXVIII). The virtual restriction of their concentration zone to the border line region between profundal and sublittoral seems very characteristic of these larvae in Third Sister Lake. Table XXV illustrates clearly the seasonal numerical fluctuations even within the region of their own greatest concentrations. A variation from 45 to 6969 per sq. m. is certainly a significant change. The maxima for *Corethra* and *Chironomus* larvae far surpassed those for *Protenthes*, yet there were instances, particularly in the shallower depths, when *Protenthes* larvae outnumbered both the other dipterans combined.

The *Tubificidae*, considering both time and place, were perhaps the most uniform in distribution of any group within the typical profundal bottom fauna. The *Tubificidae* column in Table XXVIII shows that they were always present at all depths listed and on all occasions, except between 3 and 4 m. on November 17 and from 3 to 6 m. on November 24, 1926. In the same table, data for November 8, 1927, depicts the clearly developed concentration zone of these annelids on that date at 11.5 to 13 m. The maximum number per unit area found during this investigation was in Third Sister

Lake, at 11.5-14 m. on April 11, 1928, when the tubificid population amounted to 18,132 per sq. m. (Table XXIII). Populations of *Tubificidae* in excess of 9,000 per unit area were found at various times, between 15 and 7 m. (Tables XXII to XXV). Above the latter depth, they were never known to exceed 400 per sq. m. in this lake (Tables XXVI, XXVII).

In Table XXVIII, data on the abundance and on depth and seasonal distribution of the Hydracarina in Third Sister Lake will be found. Combinations of these data with those given in the annotated list (p. 256) will yield information on relative abundance and occurrence of various genera and species. Sharply defined zonation frequently characterized the depth distribution of these mites. The same statement applies equally to the organisms listed in the "All Others" column. Many minor features in the zonal, seasonal, and qualitative distribution of the bottom fauna were observed and several of these are illustrated in the tables. In addition, tabulation of the data has revealed other features not discussed.

The seasonal and qualitative phases of depth distribution, as observed in Douglas Lake, are shown in Table XXIX. Columns showing the occurrence and distribution of *Sphaeriidae* and Nematoda are included in that table, in addition to those given in the other tables. As expected, considering the time of year when the sampling was done, the bottom fauna counts in Douglas Lake were greatly below the maxima found in Third Sister Lake. Similarly, the magnitude of the variations was less than in Third Sister Lake. However, the same generalizations with regard to distribution apply. And to the list of various ways in which each organism differed at different seasons and depths in Third Sister Lake, still another may be added for Douglas Lake; *viz.*, each kind of animal in the benthic group varied with the season and with the depth, differently in different depressions. This fact was well illustrated by the sampling in South Fish-Tail Bay on August 4, Roberts Point depression on August 6, and Sedge Point depression on August 9, in 1928 (Table XXIX). In South Fish-Tail Bay, *Corethra* larvae were taken on the date just mentioned from 12 to 23 m., with a concentration zone at 15-18 m.; in Roberts Point depression between 10 and 22 m., with a broader concentration zone, 11-20 m.; and with the maximum at 13 m.; while in Sedge Point depression no larvae were collected above 18 m. and a true concentration zone was lacking.

Depression individuality was even more distinctly shown by the comparative distribution of *Protenthes* larvae on the same dates. In South Fish-Tail Bay, these larvae extended from 10.5 to 18 m. with a sharp concentration zone at the 13 m. level; in Roberts Point depression they showed an irregular distribution between 10 and 22 m.; while in Sedge Point depression they were taken only at the 20 m. level and there in very small numbers. The discussion might be extended to the other forms and dates but the two examples described will serve to illustrate the point.

Both the *Sphaeriidae* and the Nematoda showed considerable variation in their distribution at different depths in the different depressions. The most significant data, from the seasonal aspect, obtained in Douglas Lake was that for October 20, 1928, in Roberts Point and South Fish-Tail depressions (end of Table XXIX). Not only were the quantitative changes mentioned before apparent, but marked changes of a qualitative nature and in depth distribution had occurred since these two depressions were last visited, late in August. If the data for these dates are compared with those for the same depressions on other dates, as for instance those for South Fish-Tail depression on June 22, 1928, or July 7, 1926, and those for Roberts Point depression on July 12 or August 6, 1928, the seasonal and qualitative variations are evident.

Maple Point depression, Douglas Lake (Fig. 3) was practically ignored throughout this investigation since occasional sampling there never yielded any bottom organisms. This was in sharp contrast to results obtained in other depressions at comparable depths and dates, as for instance, on August 3, 1926, at 17 m. in Roberts Point depressions where *Corethra*, *Chironomus*, *Protenthes*, *Tubificidae*, *Sphaeriidae*, Nematoda and *Sialis* were all represented. The bottom near the center of North Fish-Tail Bay (Station 60) and at a position about midway between the two points at the entrance to the bay (Station 70) usually yielded a fairly large summer benthic fauna. Station 60 frequently was the more productive of the two although this was not always the case. Hydrachnids were more often taken at these stations than elsewhere in the lake. Grapevine Channel was usually a productive region in terms of bottom fauna. More nematodes were taken in the Channel than at any other point. On several occasions, samples were taken in the various interdepression regions, as for instance, between Station 30 and Station 50 and the counts of animals often were higher than in samples from the same depth within the edges of the major depressions (Table XXX).

Kirkville Green Lake was unique in many ways, particularly in regard to bottom fauna. Between the depths of 1 and 61 m. not a single specimen of *Corethra*, *Chironomus*, *Protenthes* or *Tubificidae* was taken in 145 bottom samples (Table XXXI). Hydracarina, Gastropoda and Crustacea were found down to depths of 5 m. Below that depth no bottom animals whatever were collected. So far as macroscopic benthic animals are concerned, by far the larger part of the lake floor was absolutely barren.

ECOLOGICAL RELATIONS

FACTORS INFLUENCING VARIATION AND DISTRIBUTION

The environmental factors which affect seasonal variations, both qualitative and quantitative, and depth distribution of profundal bottom animals are of three general kinds: biological, chemical and physical. Specifically, light, temperature, water movement, chemical content of superimposed water, char-

acter of bottom, food, enemies and the life cycles of the animals involved are among the factors which might affect some or all of these activities of the benthic animals. The two interrelated phenomena of seasonal variation and distribution are both affected by the same set of ecological factors. Hence it is logical to consider them together.

Bottom Characteristics

Within the regions sampled, the various types of bottoms might be classified as sand, marl, clay and mud. The mud bottom was most typical of the profundal and lower sublittoral. However, the nature of this type of bottom deposit was not always uniform. As previously shown, the mud varied in amount of water, organic detritus and coarse debris, which it contained. It also varied in color, odor, rate of settling when stirred up, and in its tendency to rise to the surface and form floating masses.

Bottom deposits provide support and protection for the benthic fauna. With the exception of *Corethra* larvae and the adult stages of this and other insects the profundal benthic animals spend their entire existence on or in the bottom. Tube-building and burrowing of chironomid larvae and tubificids are well known.

The question was raised whether the Ekman-Birge dredge missed some of the bottom animals in the muddy water above and in the deeper mud beneath the level sampled. This possibility was thoroughly investigated early in the work. Much direct observation in the field and certain laboratory experiments demonstrated conclusively that, with rare exceptions, the bottom animals occupy the middle strata of the samples taken with the Ekman-Birge dredge. Neither the watery layer at the top nor the deeper mud layers at the bottom of these samples contained benthic animals.

In a few instances, *Corethra* larvae were kept for a time in bottles containing a concentrated live plankton collection. Under such conditions, these larvae soon showed a digestive tract filled with plankton organisms. In aquaria, with very little plankton but plenty of profundal mud, *Corethra* larvae frequently fed on the detritus. On several occasions, dissection of *Chironomus*, *Protenthes* and tubificids showed that all had been feeding on organic detritus. Ordinarily, there appeared to be more fine sand grains in the digestive tract of the tubificids than in those of the insect larvae. This fact seemed to suggest the possibility of a certain amount of selection by the larvae but it may, of course, have been accidental. Similar observations have been made by other investigators on the bottom animals in other waters.

That the character of the bottom deposits affects the nature and distribution of the bottom fauna was frequently demonstrated by sampling series. On sandy bottoms, as in Maple Point depression and on the sandy slopes of other depressions of Douglas Lake (Tables XXIX-XXX), bottom animals were few or wholly absent. When the bottom was composed of marl or a

mixture of sand and marl, as for example, in the shallower depths of Kirkville Green Lake (Table XXXI), a benthic fauna predominated by the Mollusca occurred. However, mud forms by far the greater part of the bottom deposits in the lakes studied and on the mud bottoms were encountered both the largest and some of the smallest populations. The number of animals taken in such substrata varied from the enormous populations of Third Sister Lake to complete absence in the deeper waters of Kirkville Green Lake. In Third Sister Lake, the profundal bottom deposits are a mixture of clay and black, organic detritus. In Douglas Lake, the bottom within the profundal zone is more largely black detritus and very finely divided sand, and there the numbers of bottom animals were intermediate. The character of the deeper mud deposits in Kirkville Green Lake is certainly different from that of the mud in either Third Sister or Douglas Lake. In fact, it appears to resemble the dystrophic lake deposits of Europe—the “*Torfschlamm*” or “*Dy*” of European writers. The bottom muds of Third Sister and Douglas Lakes, on the other hand, appear to be more like the “*Faulschlamm*” or “*Gyttja*” of the same investigators.

In Kirkville Green Lake, the only bottom fauna taken was from the shallow water where the bottom deposits were mixed with sand, marl, or clay. In Third Sister Lake, the bottom fauna was greatly decreased within the 5-3 m. zone (Figs. 32-46; Tables XXVII-XXVIII) and in this region, the bottom had a very large proportion of coarse, decaying plant remains and practically none of the clay-detritus of the profundal and lower sublittoral. Bottom deposits within the profundal region of Douglas Lake varied somewhat in different depressions, but these variations were always of a secondary nature. In all depressions, the same black detritus was present in considerable quantities. Likewise, variations in the profundal fauna, both qualitative and quantitative, occurred in different depressions, but these seemed not to be clearly correlated with differences of bottom mud. Certainly no such correlations between variations within the fauna and bottom deposits occurred within the true profundal region of Douglas Lake as within the sublittoral and the lower littoral. There the pronounced changes in character of bottom deposits were clearly reflected in changes within the fauna.

Physical-Chemical Factors

Physical-chemical conditions of the benthic habitat are controlled largely by the superimposed water. The great significance of thermal-chemical stratification and stagnation is accordingly evident. Consequently it was thought necessary to make frequent, complete vertical series of physical-chemical determinations from surface to lake bottom. Such determinations were ordinarily made where the water was deepest.

Three special series of determinations were made in Third Sister Lake to determine whether or not the values found for any given factor at a particular

THIRD SISTER LAKE

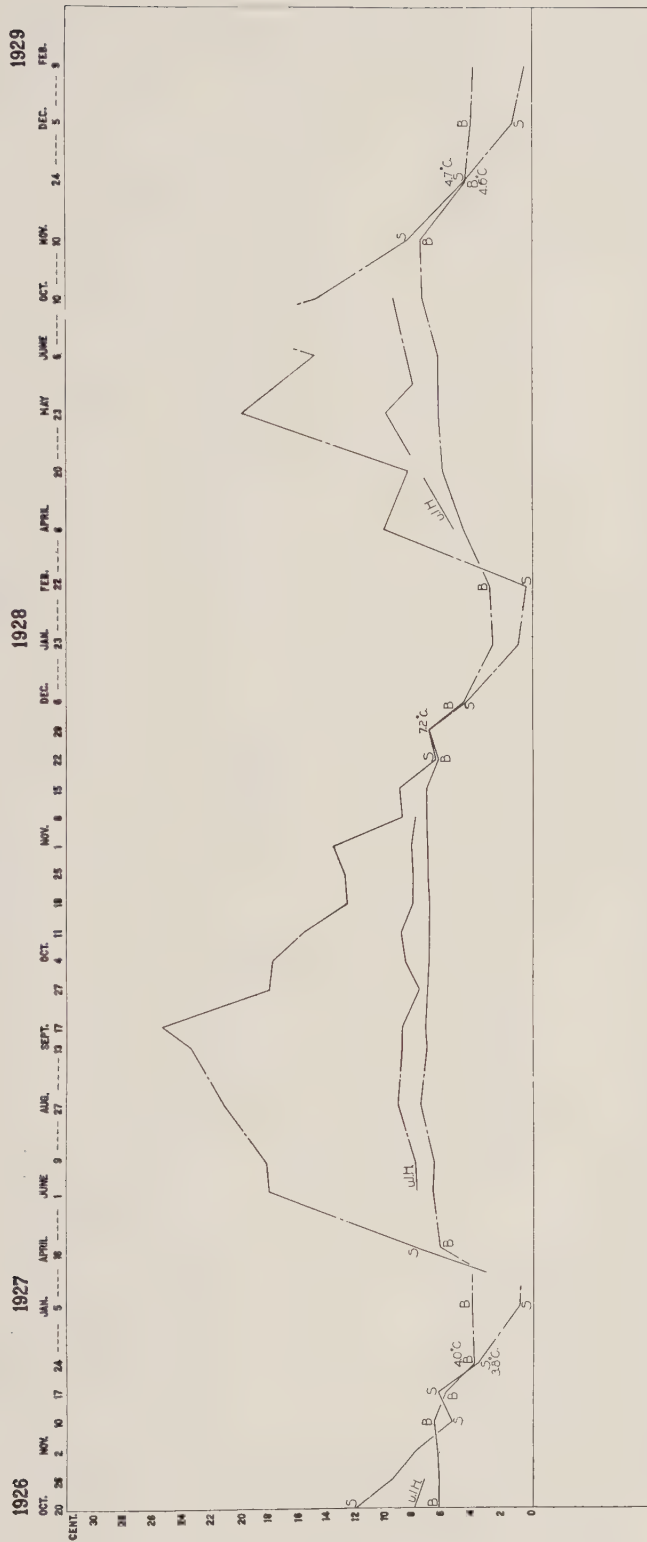


FIG. 59. Seasonal variation of water temperature in Third Sister Lake at the surface (S), upper limit of the hypolimnion (u.l.H.), and bottom (B) in degrees Centigrade.

THIRD SISTER LAKE

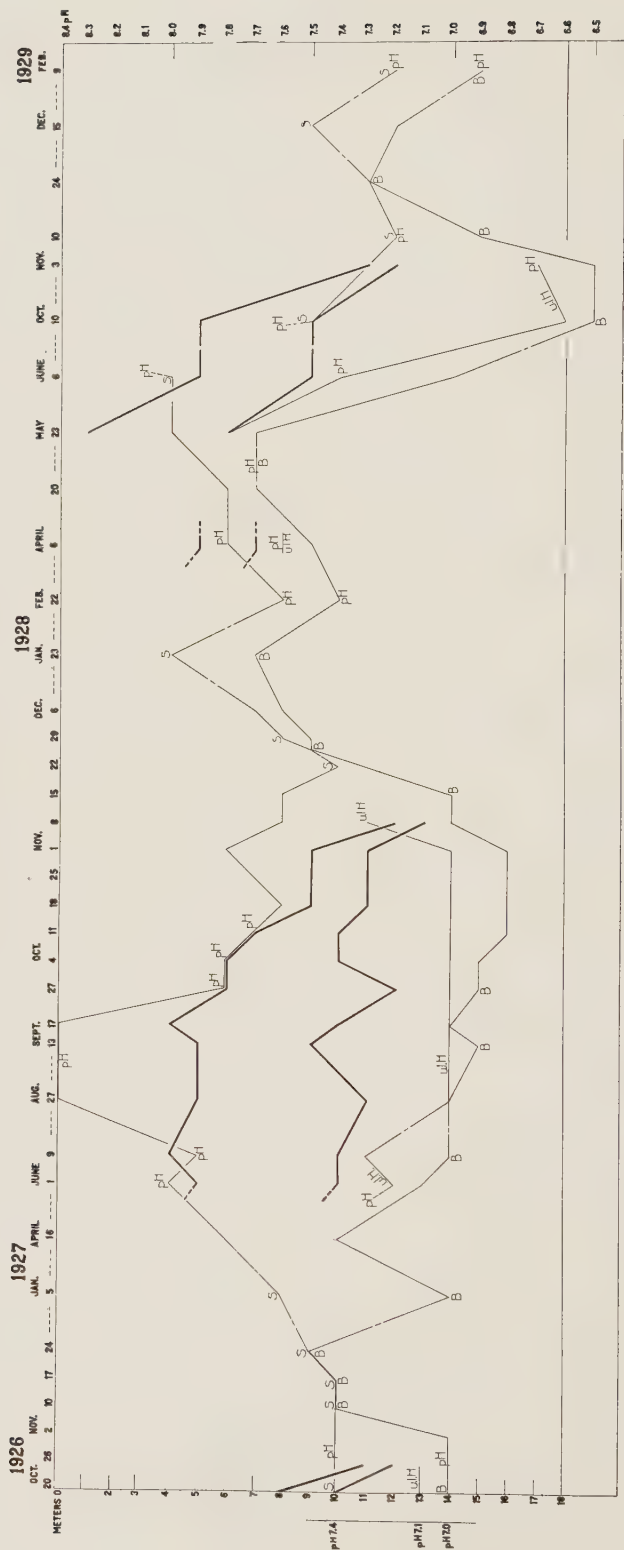


FIG. 60. Seasonal variation of pH in Third Sister Lake at the surface (S), upper limit of the hypolimnion (u.l.H.), and bottom (B). The fluctuations of the pH are shown by the light lines. Position, extent and duration of the thermocline is indicated by the heavy lines; the upper heavy line thus indicating the level of the upper limit of the thermocline and the lower giving the bottom of the thermocline at any date.

The graph displays atmospheric data from 1926 to 1928. The x-axis represents time, with months and years labeled. The y-axis has multiple scales: CO₂ in ppm (0 to 10), O₂ in cc per l (0 to 10), and a secondary scale for CO₂ in ppm (0 to 10). The graph shows several data series, including CO₂ (solid lines), O₂ (dashed lines), and a series labeled 'S' (solid lines). The data shows seasonal fluctuations and trends over the three-year period.

Fig. 61. Seasonal variation of dissolved oxygen (O_2) in cc. per liter and free carbon dioxide in parts per million at the surface (S), upper limit of the hypolimnion (u.l.H.) and bottom (B) in Third Sister Lake.

depth over the deep water were the same where that stratum came in contact with the sloping sides of the basin (Table XXXII). In these analyses, the samples were taken just above the bottom at selected depths. The first water drawn from the sampler was discarded on account of its turbidity and the clear water used for analysis. On the same days that these analyses of bottom water were made, complete vertical physical-chemical series were taken where the water was deepest, (Table XXXIII). Comparison of Tables XXXII and XXXIII will show that data for any given stratum in the deeper water always varied slightly from those taken where the same stratum was in contact with the slope of the lake basin. However, the differences found were never great. Oxygen content of the water was usually a little lower at the periphery of a particular stratum than in the deepest water, free carbon dioxide was higher, and pH readings usually showed the water to be slightly less alkaline. Temperature differences were always very small. These very slight dissimilarities might easily have been due to the influence of the bottom mud. The results indicated, however, that physical-chemical conditions of the water for each stratum of the lake (or of the individual depression in Douglas Lake) were very nearly the same where that stratum came in contact with the lake floor as over the deeper water. Thus, in considering the environmental conditions on the lake floor, at any particular depth, *e.g.*, at 7-8 m. in Third Sister Lake, it is safe to use the physical-chemical data for the same depth from the vertical series taken on the same date although such data were secured over the deepest water. Table XXXIV gives data for physical-chemical determinations in various extra-depression regions and shows that in Douglas Lake stratification was rarely found outside the depressions. These determinations were all from shallow water and are thus comparable with those from near the surface (0-10 m.) above the depressions.

A pronounced correlation between seasonal qualitative-quantitative variations of profundal bottom fauna within the true profundal zone, Third Sister Lake, and the seasonal cycle of physical-chemical factors was evident throughout the investigation. Figures 59-61 present a summary of the seasonal cycle of physical-chemical factors between October, 1926, and February, 1929. The curves in these figures show surface, upper limit of hypolimnion and bottom values for pH, dissolved oxygen in cc. per l., free carbon dioxide in p.p.m., and temperature in degrees centigrade. Figure 60 also indicates the position, extent and duration of the thermocline. These curves show two summer stagnation periods (1927 and 1928) and the close of a third (October, 1926), three periods of typical winter conditions (January, 1927; January, 1928; February, 1929), and five autumnal and vernal overturns.

If seasonal variations of bottom fauna within the profundal zone (Fig. 12) are compared with data presented in these curves, it will be seen that the three annual minima for bottom animals (late summer and early fall, 1926, 1927, 1928) coincide with periods of extreme physical-chemical stagnation.

During late October, 1926, the dissolved oxygen had entirely disappeared from the whole hypolimnion; the pH varied from 7.1 to 7.0; and the free carbon dioxide from 9 to 13 p.p.m. within the same region of the lake. Coincident with this condition, there occurred a minimum of benthic animals in this zone. That similar coincidence of severe stagnation and reduced profundal bottom population beneath the deeper waters existed during the late summer and early autumn of the other two years, is shown by the curves. The profundal fauna within the 18 m. contour (Fig. 12) also manifested three clearly developed periods of maximal abundance. These maxima occurred when temperature in the profundal zone was near 4.0 degrees Centigrade, dissolved oxygen not less than 2.0 cc. per l., free carbon dioxide varying between 3 and 11 p.p.m., and pH between 7.7. and 6.9.

The autumnal overturn greatly affects the qualitative and quantitative aspects of the benthic fauna as is strikingly shown by the records for Third Sister and Douglas Lakes. The sudden increase in bottom population beneath the 18 m. contour in Third Sister Lake each autumn during November has already been pointed out. Reference to Table XX will show that between October 26 and November 2, 1926, the total population per sq. m. within the 18 m. area increased from 7,725 to 12,836. Figures 59-61 show that a thermocline was present on the former date but that on the latter the autumnal circulation period had begun. Within the next eight days, the bottom population rose to 29,688 per sq. m. and within that time the whole lake had become thermally and chemically uniform. Again, on November 1, 1927, the count for bottom animals within the 18 m. area was 7,360 per sq. m. while one week later, it was more than 16,200, and by November 21 the population exceeded 37,700. During this same three weeks, the thermocline had been obliterated, the whole lake set in circulation, and the summer stagnation relieved. Once more in November, 1928, the bottom population at 18 m. rose from 4,916 to 30,648 per sq. m. within 14 days and coincidently the fall overturn had set in.

In Douglas Lake, the only fall records are those for October 20, 1928 (Tables VI, XI, XXIX). On that date, both South Fish-Tail and Roberts Point depressions were practically uniform, from surface to bottom, thermally and chemically. Both depressions were thermally stratified when the last summer readings were taken, and showed well developed, typical summer stagnation, with a hypolimnion wholly devoid of dissolved oxygen. Also, the bottom fauna counts were low in both depressions. On October 20, however, the bottom populations found in these depressions were by far the highest which have been recorded for this lake. In Roberts Point depression, the circulation had become more complete and correlated therewith was a wider dispersion of bottom fauna than in the South Fish-Tail depression.

A further correlation between degree of stagnation within the hypolimnion and variations within the profundal bottom fauna is to be found in the qualitative and quantitative differences between the bottom fauna in different

depressions during the same summer. Records of physical-chemical determinations show that South Fish-Tail, Sedge Point, Roberts Point, and Fairy Island depressions are, with rare exceptions, thermally and chemically stratified throughout each summer and that stagnation becomes rather pronounced in each of them by late July or early August. The faunal records (Tables XIV-XVII) also show that these same depressions rarely have any species other than the typical profundal fauna within their deeper profundal regions during the summer, and that these types also dwindle to an annual minimum in late summer. On the other hand, Grapevine Point and Stony Point depressions frequently show a complete lack of thermal-chemical stratification (Tables VII, X) and correlated with this the faunal records (Tables XVIII, XIX) show, not only a greater variety of species present in the deeper profundal region ("All Others" column in tables), but also more individuals among the typical profundal species than are present in those depressions characterized by a stagnant hypolimnion during the summer months.

Formation and obliteration of the bottom fauna concentration zone in Third Sister Lake was found to follow the seasonal cycle of stagnation and circulation. As summer stratification set in the concentration zone began to form. However, this concentration of benthic animals was not simply a response to onset of summer stagnation. This is evident from the fact that it had begun to form as early as April 11, 1928 (Fig. 42), and by June 6 of that year (Fig. 43) had reached its typical summer form. Other factors contributing to the complex which brings about this zonation of bottom fauna are considered on following pages. Reference to Figures 59-61 will show that on April 11 there was an abundance of dissolved oxygen throughout the hypolimnion and that while a thermocline was present, it later disappeared. It can hardly be said, then, that the stimulus which had initiated formation of the concentration zone was the beginning of summer stagnation. Mere formation of a thermocline could not be supposed to greatly influence, directly and so quickly, the distribution of benthic animals. But it seems just as evident, when the data are all considered, that, once the concentration zone is established, development by that time of profundal stagnation does act as a barrier to prevent dispersal of this fauna over the entire profundal region of the lake floor. Consequently, when the concentration zone had reached its typical summer form by June 6, 1928, the population of that zone was deterred from spreading over the whole lake floor by the comparatively severe stagnation within the deeper regions of the lake (Figs. 59-61).

With the coming of the autumnal circulation (Figs. 59-61) the concentration zone began to shift into deeper water (Figs. 44-46), or in other words, as the thermocline gradually sank more and more of the profundal bottom was released from stagnation, and as this release progressed the bottom animals followed it down the slope. Soon the lake became nearly homothermous from top to bottom and the whole body of water was set in circulation.

That this circulation is not a mere figure of speech, but rather, that actual currents of considerable strength are set up (under the combined influence of the strong fall winds and the now nearly uniform density of the water) which sweep along the profundal lake bottom, was clearly demonstrated during November, 1926, 1927 and 1928. Furthermore, that these currents are of considerable direct, as well as indirect, importance in the life of the bottom animals, was indicated by certain incidental but significant observations which the writer was able to make each autumn.

During much of the time between October, 1926, and December, 1928, experiments were in progress which required keeping glass containers on the lake floor within the deepest region of Third Sister Lake. Such containers were placed in cubical baskets constructed of coarse mesh wire netting. These baskets rested on the upper surface of the firm mud bottom. Each autumn and spring when the overturns were in progress the baskets, when brought to the surface, contained quantities of tree leaves, bits of shoreward vegetation, twigs, and on many occasions Odonata and Ephemera nymphs. On November 24, 1928, one basket contained a small sunfish, alive and active, and, in addition, several Odonata nymphs. On November 29, 1927, several active leeches (*Erpodella punctata* and *Glossiphonia complanata*), many damselfly nymphs, and a few dragon fly nymphs were found in one basket. Another basket contained a small (6 cm.) *Ameiurus natalis* in addition to a single large leech. Similar observations were made on numerous other occasions during the periods of most active circulation in the lake. Such material never was found in the baskets except during autumnal and vernal overturns, and more was usually found in fall than in spring. It seems entirely reasonable to suppose that currents which would transport this heterogeneous collection of shoreward debris, and at least assist the scattering of littoral organisms, might also have a part in the autumnal dispersal of profundal bottom fauna.

Many instances indicating the effect of fall overturns and relief from stagnation could be cited from the data. Comparing the data presented in Figs. 59-61 with such variations as were shown by Protenthes larvae between October 10 and November 10, 1928 (Table XXVIII) or with that shown by Chironomus larvae in the 9-10 meter depth for various seasons (Table XXIV), will serve to illustrate what is meant. However, probably the most convincing evidence relative to the effect of overturns and stagnation is presented when the unanimity in general trend of variations, both qualitative and quantitative, for all depths and all seasons, is considered in the light of the whole seasonal cycle of physical-chemical factors.

Available evidence (p. 253) suggests the possibility that Kirkville Green Lake may never have a complete circulation of its profundal waters. The data for April 15, 1925 (Fig. 6), suggests that the lake was nearly homothermous throughout some time earlier in the same month, but its protection from wind is so complete and the slope of its bottom is so steep that the whole central

known number of specimens, usually 100, in 2-quart, glass, fruit jars; fill the jars with water; and in some instances add a little bottom mud; place the numbered jars in baskets constructed of galvanized wire netting; and suspend them at the desired level in the lake by means of equipment shown in Fig. 62. Some of the jars were carefully filled with oxygen-free water collected just above the bottom within the hypolimnion when stagnation conditions prevailed. Filling was done by introducing a long tube from the water sampler outlet to the bottom of the jar which was then overflowed for some time after it was full. Samples of the water used were analyzed for pH, dissolved oxygen, free carbon dioxide, and, in some instances, carbonates and bicarbonates, at the time of filling and at the close of the experiments. Temperature was also recorded at the same times. A little, profundal mud which had been passed through a fine screen was added and into these jars were counted, from material freshly collected from deep water, a number of individuals of the different species of bottom animals. Usually representatives of but one genus were placed in a jar. Some of these containers were sealed in such a way as to include no air bubble; others were covered with a cap of fine-mesh, cloth netting. These jars, both open and closed, were lowered in a basket to the bottom where stagnation conditions were known to occur.

Controls were provided by placing in duplicate jars equal numbers of the same forms taken from the same collection. These control jars were filled with surface water. Profundal bottom mud was added to some; mud from the sublittoral to others; and still others contained no mud. In some of the experiments of this series, the control jars were filled to overflowing with surface water and sealed with no air bubble included; other jars were filled about one-half full of surface water and then sealed with a large air space; and still others were covered with the same kind of cloth netting used on the jars in the hypolimnion, and thus left open to the water. These controls were then lowered to a lake level known to be above the thermocline and in well aerated water. Such experiments were conducted in Douglas Lake during the summers of 1926, 1927 and 1928 and in Third Sister Lake during the summers of 1927 and 1928.

No two among the different species showed the same degree of resistance to the conditions imposed by stagnation. There was also a wide range of individual variation in resistance. In every experiment conducted, however, if it was continued long enough and under conditions which were severe enough, all *Corethra*, *Chironomus* and *Protenthes* larvae died. In no experiment did all *Tubificidae* or *Pisidium* die, although in two instances about 80 per cent died during an exposure of a little less than three months at 18 m. in Third Sister Lake during June, July and August. In all experiments, some individuals died in each jar, both experimental and control. This may have been caused by handling when they were placed in the jars, or those individuals might have been about to die from some other cause when collected.

In all instances, however, more individuals, usually many more, died in jars which were filled with water from the stagnation zone than in control jars. Results were not consistent in regard to which species of bottom animals showed the first deaths in experimental jars. Usually, however, all *Corethra* larvae were dead before all *Chironomus* or *Protenches* larvae had succumbed. The last insect larvae to die usually were individuals of the genus *Chironomus*. In general, a larger percentage of *Tubificidae* survived than of any other type used.

Series B. These experiments were conducted with the hope that something might be learned concerning relative importance to profundal benthic animals of (1) the chemical nature of superimposed stagnant water and (2) the physical factors such as pressure, darkness, and low temperatures. Methods employed were identical with those described under Series A, except that (1) experimental jars lowered to the bottom within the hypolimnion were all sealed shut; (2) some contained surface lake water; (3) others, well water having no dissolved oxygen, 1-2 p.p.m. free carbon dioxide, and a pH of 7.3-7.6; and (4) still others, water from just above the bottom in the hypolimnion. The same species of experimental animals were used as in Series A.

All the animals lived longer in jars containing surface lake water than in either of the other sets. Many animals were alive in surface water jars at the close of the experiments. The animals died in the jars containing bottom lake water (O_2 , 0.0 cc. per l.; CO_2 , 3.0 p.p.m.; pH, 7.0) more quickly than in the well water in which the dissolved oxygen, free carbon dioxide, and pH values were all somewhat similar.

Series C. The object of these experiments was to study the effect of stagnation conditions on activity of bottom animals. Jars were filled with water from just above the bottom within the hypolimnion in such a manner that no air bubble was included and otherwise treated as in Series A. The jars rested on the lake floor beneath the deeper hypolimnion. Observations regarding activity of the animals were usually made twice daily in Douglas Lake experiments, but much less frequently in Third Sister Lake experiments. Results in both lakes were uniformly similar. *Corethra* larvae and pupae remained active for a few days. Some larvae occupied various levels of the water in the jars and others, at times, burrowed into the mud. All *Corethra* larvae died if the experiments were continued for a few weeks. Sometimes they all died within one week. *Chironomus* larvae often constructed tubes in the mud and remained quite active for periods varying from 4 to 10 days. Usually most *Chironomus* larvae had become inactive within 5 days and were dead within 2 weeks. Results with *Protenches* larvae were much the same as with *Chironomus* larvae. Individuals of *Pisidium* ceased movements within a few days and, with valves tightly closed, remained inactive thereafter. Some of these sphaeriids died within 2 weeks in experimental jars, others lived for months. In one instance, such a jar was set up with bottom water on October

11; 10 specimens of *Pisidium* introduced; the jar sealed; lowered to the lake bottom; and not opened until the following May 23. When this jar was opened, 2 empty shells were recovered and 2 inactive animals were found, which, however, appeared to be alive. When placed in surface lake water, these 2 specimens opened their valves, thrust out their feet and became quite active. No trace of the remaining 6 animals or their shells was found although the mud was carefully passed through a fine mesh screen. Specimens of *Limnodrilus* remained somewhat active throughout experiments of shorter duration and many individuals survived even the longer exposures. Activity of these forms usually consisted of slowly crawling through or on the mud. On a few occasions, specimens were seen to wave one end of the body slowly in the water while the other end remained within a burrow in the mud.

Series D. In this series of experiments, the effect of stagnation conditions on reproduction and life histories of profundal bottom fauna was studied. The general methods were those described under Series A. Experiments with *Corethra* eggs and with adult specimens of *Limnodrilus* and of *Pisidium* were conducted within the hypolimnion (South Fish-Tail depression, Douglas Lake) during the summer stagnation periods. Other experiments, using *Limnodrilus* cocoons and adults, and *Pisidium* adults were performed within the profundal zone, Third Sister Lake.

In addition to the lake-bottom experiments, certain others were conducted in the laboratory using tubificid cocoons. Cocoons were placed in bottles filled with water having no dissolved oxygen, 1.0-2.5 p.p.m. of free carbon dioxide, and a pH of 7.2-7.6. Some of these bottles were kept cold (3.0-10.0 °C.) others were kept at warmer temperatures (15.0-25.0 °C.).

Controls for the experiments on *Corethra* eggs and tubificid cocoons were provided in three ways at different times. In some instances, controls consisted of eggs placed in open dishes filled with surface lake water and kept on a laboratory table; at other times, the control containers were large aquaria supplied with running surface lake water; and the third type of control was provided by placing eggs in jars filled with surface lake water and suspended within the epilimnion of the open lake.

Tubificid eggs hatched within 14-20 days after collection when kept in oxygenated water. They hatched a few days earlier in warm water (15-25°C.) than in cold water (4-10°C.). Under conditions closely resembling those of the hypolimnion during severe stagnation, some tubificid eggs developed, although not as quickly as did those in the control dishes. Not as large a percentage of the eggs hatched in experimental bottles as in the open control dishes.

Corethra eggs hatched more quickly when there was an abundance of dissolved oxygen in the water and temperature varied between 18 and 25°C. than they did when either temperature or oxygen content of the water was low. Elapsed time between laying and hatching of eggs varied between 2.5

and 13 days. No *Corethra* eggs hatched when subjected to conditions typical of deeper profundal regions during summer stagnation. Some *Corethra* eggs hatched (10-13 days after ovoposition) when placed in experimental jars which were covered with fine mesh grit-gauze and then lowered to the lake floor at a level well above the upper limit of the hypolimnion.

Experiments using mature specimens of *Limnodrilus* and of *Pisidium* were conducted in Douglas Lake during the summer and during all seasons of the year in Third Sister Lake; yet no positive evidence of reproduction of either of these organisms within experimental jars kept in the deeper profundal region was obtained.

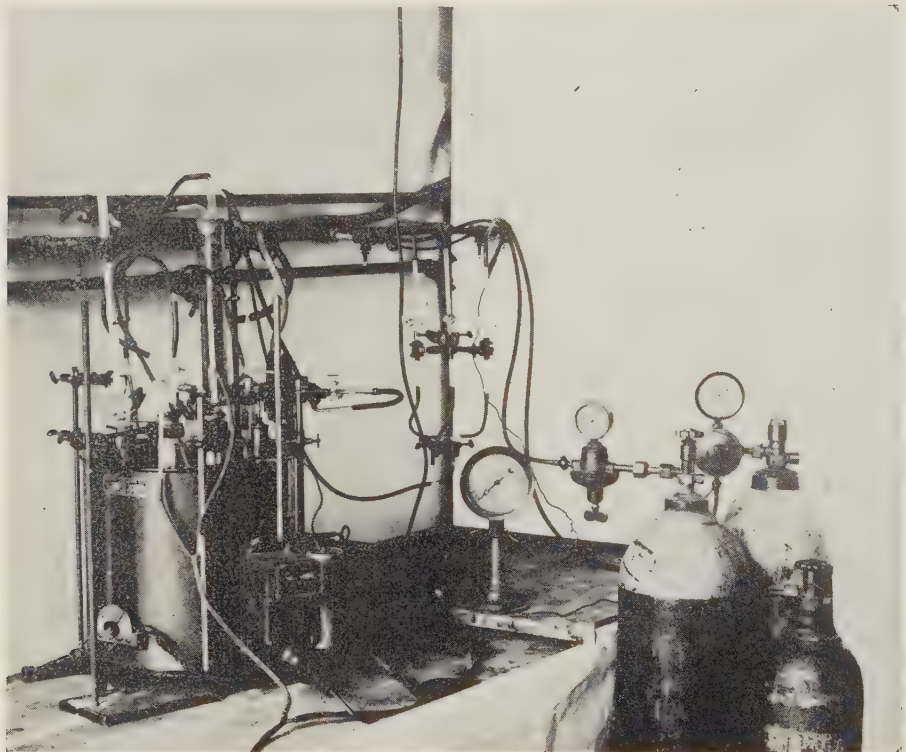


FIG. 63. Apparatus used in determining toleration ranges of profundal bottom organisms. Experimental *Series E*.

Series E. This set of experiments was conducted in the laboratory. The aim was to study toleration ranges of various benthic animals to environmental factors such as temperature, pH, free carbon dioxide, and dissolved oxygen. The apparatus used is shown in Fig. 63. High temperatures (25-50°C.) were obtained by a DeKotinsky Constant Temperature Apparatus; low temperatures by a circulating brine system, and pH was varied by introducing dilute HCL or KOH from a dropping burette into the water supply.

Dissolved oxygen, and free carbon dioxide content of the water were controlled by forcing various mixtures of oxygen, carbon dioxide and hydrogen into the water as it trickled down through a large tube filled with glass beads. Corethra, Chironomus and Protenthes larvae and, in a few instances, tubificids were used. The major portion of the experiments, however, concerned Corethra and Chironomus larvae.

None of the animals showed any sign of harm from low temperatures, even when kept in water just above the freezing point. Low oxygen content, although it always reduced activity, never resulted in a mortality significantly greater than that in control containers. This may have been due to the fact that none of these experiments were continued more than fifteen days. It is possible that longer exposure to oxygen-free water would have killed more individuals. Results of a long series of experiments using high temperatures may be summarized as follows: Corethra larvae were killed instantly by a temperature of 48°C. and died in 5 seconds at 47°C.; 2 minutes at 46°C.; 3-4 minutes at 45°C.; 40-60 minutes at 40°C.; 24-36 hours at 30°C.; but were still alive at the end of 15 days in water which varied between 20 and 25°C. Chironomus larvae were killed instantly by a temperature of 49°C.; died in 5-10 seconds at 48°C.; 40-50 seconds at 47°C.; 4-5 minutes at 45°C.; 40-60 minutes at 40°C.; 40-45 hours at 35°C.; 48-96 hours at 30°C.; but were alive and apparently normal after an exposure of 15 days to a temperature of 20-27°C.

Both Corethra and Chironomus larvae were rendered inactive within 3-5 minutes by exposures to a free carbon dioxide content of 800-900 p.p.m.; but all recovered later after exposures lasting up to 2 hours. Such experimental animals usually died, however, within 6-10 days after being subjected to these high concentrations of free carbon dioxide.

After some preliminary experiments, using certain organic acids which appeared to have a harmful effect aside from that due to the free hydrogen ion, pH was varied by using diluted solutions of hydrochloric acid or potassium hydroxide. Corethra larvae lived from 10-12 days in water having a pH of 3.0. When the pH was 6.0, 70 per cent were still alive after a 15 day exposure, but with the pH at 9.0-9.2, the larvae began dying within 3 days and all died within 14 days.

Biological Factors

Certain factors which affect life on the lake bottoms are specifically biological in their nature. It is true that these are, like others, affected by the annual physical-chemical cycle also. But despite their being influenced by such environmental conditions as temperature and chemical content of the water, they must be considered apart from such influences.

One of the most important factors influencing the quality and quantity of profundal, bottom animal life is insect transformation and emergence.

There can be no doubt that the enormous autumnal change within the deeper profundal is, in part, an actual shifting of the population, including the insect larvae, downward from the summer concentration zone. The data also indicate that a reciprocal swing in the opposite direction from deep to shallow water in the spring may be partly due to actual movement of the winter population, although any such shifting is of much less magnitude than in late autumn. But the most effective factor in the spring and early summer qualitative-quantitative reduction among the benthic fauna, and especially within the deeper profundal, is the emergence of great swarms of *Chironomus* and *Corethra* together with the less abundant *Protenthes*. In both Third Sister and Douglas Lakes, the period of marked quantitative decline among the insect larvae of the profundal benthic fauna is coincident with the most active emergence periods. The tables and figures show many examples, but a single instance will serve to illustrate the significance and magnitude of this factor. Reference to data for February 22, April 11 and June 6, 1928 (Table XXVIII), showing depth distributions of benthic animals, will reveal the effect of emergence upon that part of the bottom population which was composed of insect larvae. If these findings are compared with the "Tubificidae" column, the contrast between the effect upon total benthic population produced by the attainment of sexual maturity in those species which emerge and the effect of the same phenomenon on a species which spends all its life on the bottom will at once be apparent.

Although emergence of insects has the direct and immediate effect of bringing about great reduction in total population per sq. m., it leads to replenishment of this same population through egg laying and hatching of the next larval generation. Repeated observation on Douglas and Third Sister Lakes has convinced the author that *Corethra*, *Chironomus* and *Protenthes*, ovoposit promiscuously all over the lake surface. There may, very possibly, be more eggs laid on shoreward waters but the writer has frequently seen females ovopositing on the lake surface over the center of South Fish-Tail depression, Douglas Lake. It is well known that the eggs sink soon after deposition and thus they must reach the lake floor in deep as well as shallow water. Juday (1921, p. 274) demonstrated that mud from the profundal zone of Lake Mendota contained *Corethra* eggs. The present writer was able to confirm this finding on several occasions with mud from the profundal zone in Douglas and Third Sister Lakes. In addition, young *Chironomus* larvae appeared in two such experiments at Douglas Lake and once when profundal mud from Third Sister Lake was being used. Other experiments performed by the author (p. 293) seem to indicate that these insect eggs do not hatch within the profundal zone where the temperature is low and the water chemically stagnant during the summer, but that those eggs which reach the bottom within the littoral and sublittoral do hatch during the summer. This would tend to build up the concentration zone in the region

above that of the most extreme stagnation. It is also possible that when the fall overturn sets in those eggs which were deposited within the profundal zone (particularly those laid by the later broods) may hatch. If so, these larvae, together with those which hatched in the shallower waters during late summer, would account for the increased total population for the whole lake in the late fall. Sharp autumnal decline of insect emergence; possible hatching of insect eggs beneath the deeper waters when stagnation is relieved; definite obliteration of the shallow water concentration zone and shifting of its massed population downward along the sloping lake floor, exemplify the interplay of various environmental factors which brings about the striking quantitative variations and depth distribution changes characteristic of the profundal benthic fauna when the fall overturn is in progress.

The tubificids in Douglas Lake were rarely found sexually mature during the summer. In October, 1928, however, many sexually mature specimens and a few cocoons were collected in bottom samples. Third Sister Lake yielded many sexually mature specimens and some cocoons each year in November. However, from February to the middle of April, each year, was the period when the largest proportion of sexually mature worms was collected and also during that period the greatest numbers of cocoons were taken. Following the appearance of the cocoons there was always a great increase in the total numbers of tubificids and many of these worms were small and immature. These periods of reproduction correspond with and explain their large numerical increases in Third Sister Lake. It seems probable that the greatest effect of the overturns on the *Tubificidae* is an acceleration of sexual maturity and activity, since these periods of circulation coincide roughly with the periods of maximum occurrence of cocoons and since the experiments described previously appear to show that some tubificid cocoons may develop even during stagnation within the profundal zone.

The possibility that the numbers of *Corethra* larvae swimming in the open water of the lake might be large enough to materially reduce the population left in the bottom mud was considered early in this investigation. Juday (1921) has shown that in Lake Mendota there is a considerable migration of full-grown *Corethra* larvae from bottom mud into the water during the night, but that young larvae occupy bottom water instead of the mud during the day; also that young larvae, "were found regularly in the net catches from the latter part of June to the first week in October."

The author made vertical hauls with a closing plankton net on many occasions during the course of this investigation, both in Douglas and in Third Sister Lakes. Only rarely were *Corethra* larvae of any age taken in Douglas Lake above depths of 10 meters in the daytime during June, July, and August. In Third Sister Lake, conditions with respect to presence of *Corethra* larvae in the water were quite different and there was a marked lack of consistency in the way larvae were distributed in the water on differ-

ent occasions. Usually they were present in the water up to a depth of 5 m. during the day. On certain occasions, they were found occupying the water at all levels from bottom to the surface, while at other times they were not found above the 15 m. level during the day. The whole question of diurnal migration of these larvae, in both lakes, is receiving further study and the results will be presented in a later paper.

SUMMARY

1. Physiography of the lakes is discussed; a hydrographic map of Third Sister Lake is given; and certain morphometric data relating principally to Douglas and Third Sister Lakes, are presented.

2. The extent and characteristics of the three benthic zones, littoral, sublittoral and profundal, in certain lakes, were investigated.

3. Douglas and Third Sister Lakes were found to have profundal zones of considerable extent and the profundal benthic habitat in each was studied in relation to (1) bottom deposits and (2) physical-chemical conditions of the superimposed water, as revealed by more than 180 vertical series of thermal-chemical determinations.

4. Qualitative-quantitative counts of bottom animals, based on a total of 1879 bottom samples from three lakes, showed the presence of a typical profundal benthic fauna in two of the lakes.

5. The organisms collected on the bottom form two ecological groups: (1) a typical profundal bottom fauna, comprising representatives of the genera *Corethra*, *Chironomus*, *Protenthes*, *Limnodrilus*, *Pisidium*, *Muscilium*, and *Hydromermis*; and (2) a heterogeneous group of benthic types in which the Insecta were represented by 7 species; the Pelecypoda by 10; Hirudinea, 2; Hydracarina and Gastropoda, 13 each; and the Ostracoda and Nematoda, 1 species each.

6. Seasonal variation of *the typical profundal bottom fauna within the true profundal zone* showed the following general features for Douglas and Third Sister Lakes:

(a) *Corethra* larvae, always present in both lakes, were the most abundant inhabitants of the profundal zone, attaining a maximum population of more than 70,000 per sq. m.

(b) *Limnodrilus* was always present in Third Sister Lake and usually present in Douglas Lake.

(c) At certain times of the year in both lakes, all other typical profundal types were apparently absent except perhaps as eggs.

(d) Fluctuations of total profundal bottom fauna showed a marked periodicity with annual mid-summer minima and mid-winter maxima.

(e) Following the mid-summer minimum there was a slight and very slow increase in total population until late fall, when a very sudden and very large increase took place in the deepest regions of the lake.

(f) The decline leading to the mid-summer minimum began in early spring.

7. Data obtained from sampling series demonstrated that for profundal bottom animals the two major aspects of distribution are zonal and seasonal. The principal results may be summarized as follows:

(a) The distribution was not uniform from deep to shallow water.

(b) A concentration zone occurred in the upper profundal and lower sublittoral regions during the summer and the total population per unit area of bottom declined sharply above and below this zone.

(c) This concentration zone shifted downward into deeper water in the fall; occupied the deepest profundal during the winter; and then shifted up toward the summer level during the spring.

(d) The number of species and the number of individuals per unit area varied with the season, differently at each different depth, and in Douglas Lake, differently in each different depression.

(e) The number and kind of species and the number of individuals per unit area varied greatly in different lakes and in different parts of the same lake.

8. Ecological factors found to influence qualitative-quantitative variations and distribution were (a) bottom characteristics; (b) physical-chemical nature of the superimposed water; and (c) certain biological phenomena.

9. Both the densest and some of the most scanty populations were found on muddy bottoms. Complete absence of bottom animals occurred on (a) bottoms of clean sand and (b) muddy bottoms which had become very foul.

10. Chemical stagnation in the hypolimnion was found to be an important factor in the ecology of the profundal benthic fauna.

11. The semi-annual overturns produced very pronounced changes in the benthic population of the deeper profundal zone.

12. Emergence and egg laying of insects, variations in sexual activity of other benthic types, and the rate and time of hatching of eggs on the lake floor are all influenced by the physical-chemical seasonal cycle and, in turn, greatly affect the qualitative-quantitative variations of the profundal benthic population.

13. The profundal benthic fauna forms a very distinct ecological association, qualitatively limited by the severity of the habitat, but becoming quantitatively very rich at certain seasons.

14. It appears probable that the profundal benthic association has been derived from the sublittoral fauna and this in turn from the fauna of the littoral zone.

15. Considering the interplay of physical, chemical, and biological factors of the environment, it seems evident that the pronounced effectiveness of the physical-chemical stagnation is due not to the variations of any one factor in

the complex, but rather to the combined action of variations of each factor in the presence of variations of the others.

16. Evidence now available indicates that the members of the profundal benthic fauna are facultative rather than obligatory "anaerobes" and that they endure rather than select an anaerobic environment.

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EXPLANATION OF TABLES V TO XXXIV

In the tables showing variations of physical factors, temperatures are expressed in degrees Centigrade; depths in meters; dissolved oxygen in cubic centimeters per liter; free carbon dioxide in parts per million; and methyl orange alkalinity in parts per million of calcium carbonate.

Abbreviations: *S.*, surface; *u.l.H.*, upper limit of the hypolimnion; *B.*, bottom; *N.S.*, no stratification; *cc. per l.*, cubic centimeters per liter; *p.p.m.*, parts per million; *M.O.*, methyl orange; *pH*, hydrogen ion concentration; *Cor.*, Corethra; *Chir.*, Chironomus; *Prot.*, Protenthes; *Tub.*, Tubificidae; *Suc.*, Succinea; *Phy.*, Physa; *Val.*, Valvata; *Gon.*, Goniobasis; *Plan.*, Planorbis. Other abbreviations used are all too well known to need explanation.

TABLE V. *Analysis of bottom mud.*

Station No.	Depression	Depth meters	Weight, in grams, of				Wet Mud		Dry Mud	
			Wet Mud	Dry Mud	Residue after ignition	Loss on ignition	% water	% solid matter	% non-volatile matter	% volatile matter
1	South Fish-Tail...	24	1030.7	84.52	56.59	27.93	91.8	8.2	67.0	33.0
30	Fairy Island.....	28	1042.6	86.54	58.05	28.49	91.7	8.3	67.1	32.9
10	Grapevine Point...	25	1044.2	108.6	74.76	33.84	89.6	10.4	68.8	31.2
50	Robert's Point.....	22	1051.15	118.78	82.55	36.23	88.7	11.3	69.5	30.5
20	Sedge Point.....	24	1053.04	120.8	85.77	35.03	88.5	11.5	71.0	29.0
40	Stony Point.....	19	1058.45	150.3	114.2	36.07	85.8	14.2	76.0	24.0
(1a)	Third Sister Lake..	18	1582.3	857.4	792.7	67.70	45.8	54.2	92.1	7.9
(1b)	" "	18	1062.4	201.2	129.7	71.50	81.1	18.9	64.5	35.5
(1c)	" "	18	2113.0	1519.5	1456.0	63.50	28.1	71.9	95.9	4.1

Samples from each of the 6 major depressions of Douglas Lake and from the 18 m. depth of Third Sister Lake. Volume of mud = 1000 cc. in each sample.
1a—Bottom mud as it occurs in the lake, i.e. alternate layers of 1b and 1c (mixed together in this sample).
1b—A sample of the black organic detritus layers.
1c—A sample of the gray clay layers.

TABLE VI. Seasonal variation of physical-chemical factors.
South Fish-Tail depression—Douglas Lake.

Station 1

23 meters

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923																	
July 5	22.1	10.7	8.5	12-15	7.1	8.4	7.4	7.3	4.26	2.9	0.28						
9	22.2	9.7	8.3	11-15	8.8	8.4	7.6	7.2	5.1	2.1	0.08						
13	23.9	11.5	8.5	11-15	7.9	8.4	7.6	7.2	5.27	2.51	0.70						
19	23.7	11.5	8.0	11-15	7.8	8.4	7.4	7.2	3.49	0.84	0.06						
24	22.8	10.2	8.5	9-15	11.4	8.4	7.3	7.1	4.54	1.93	0.0	0.0	5.0	15.0	117	118	126
27	21.1	10.8	8.4	9-14	10.2	8.2	7.2	7.1	4.54	1.93	0.0	0.0	1.0	12.0	119	120	130
31	21.7	10.0	8.3	9-15	10.0	8.2	7.2	7.1	4.07	1.60	0.0	0.0	6.0	9.5	120	127	136
Aug. 6	22.5	9.8	8.3	11-15	9.7	8.2	7.2	7.1	6.07	1.60	0.0	0.0	7.0	16.0	120	127	136
16	21.8	9.4	8.8	11-15	10.4	8.1	7.2	7.1	6.21	0.97	0.0	0.0	10.0	19.0	124	128	135
1926																	
June 22	17.2	6.9	6.8	16-18	6.7	8.4	7.8	7.3	6.05	0.61	0.0						
July 1	19.0	9.8	6.5	15-18	6.0	8.4	7.3	7.2	6.16	0.00	0.0	0.0	15.0	19.0	126	129	130
13	18.7	9.6	6.9	15-20	9.9	8.4	7.2	7.2	3.52	0.66	0.0	0.0	5.0	16.0	124	130	136
22	22.3	9.9	7.3	14-18	8.1	8.4	7.2	7.2	6.28	0.0	0.0	0.0	10.0	13.0	125	129	131
Aug. 9	22.7	9.7	7.6	15-19	7.1	8.5	7.2	7.1	5.88	0.0	0.0	0.0	11.0	16.0	129	140	142
13	21.0	9.1	7.7	14-19	9.2	8.5	7.2	7.1	6.77	0.0	0.0	0.0	11.0	19.0	125	130	138
26	19.3	10.1	8.2	15-19	7.9	8.5	7.2	7.0									
1927																	
June 24	18.4	16.6	11.7	8-9	1.0				5.58	5.44	0.0	0.0	0.0	8.0	118	115	123
July 2	23.4	19.9	10.7	6-8	2.9	8.4	8.3	7.3	6.00	2.86	0.14	0.0	3.0	9.0	117	122	124
6	20.2	13.2	11.0	12-15	5.4	8.4	7.6	7.3	5.58	0.00	0.0	0.0	8.0	13.0	117	123	127
27	21.2	11.5	10.9	12-18	8.0	8.4	7.1	7.1	6.14	0.00	0.0	0.0	11.0	13.0	114	123	123
Aug. 15	20.4	11.5	11.0	16-20	6.7	8.4	7.1	7.0									
1928																	
June 22	19.9	10.4	9.0	13-19	5.6	8.4	7.1	7.1	5.37	1.60	0.0	0.0	5.0	11.0	114	125	126
27	17.6	11.1	9.4	15-17	3.3	8.4	7.1	7.0	5.40	0.20	0.0	0.0	7.0	12.0	118	125	127
July 4	20.9	11.3	9.6	13-17	5.7	8.2	7.2	6.9	5.38	0.19	0.0	0.0	7.0	15.0	111	122	124
21	21.7	12.2	9.9	11-17	8.3	8.0	7.1	6.9	5.44	0.03	0.0	0.0	9.0	12.0	115	123	126
Aug. 12	23.2	11.8	10.6	13-18	8.3	8.2	7.0	6.9	5.44	0.03	0.0	0.0	9.0	12.0	115	123	126
14	24.2	11.6	10.6	13-18	8.5	8.2	7.0	6.8	...	0.0	0.0	0.0	9.0	12.0	...	123	125
Oct. 20	11.4	N.S.	10.9	N.S.	N.S.	7.8	N.S.	7.8	7.24	N.S.	6.34	1.5	N.S.	2.0	180	N.S.	152

TABLE VII. Seasonal variation of physical-chemical factors.
Grapevine Point depression—Douglas Lake.

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923 Aug. 18	20.8	11.0	9.4	12-18	9.4	8.4	7.1	7.0									
1926 July 14	19.5	N.S.	18.3	N.S.	N.S.	8.4	N.S.	8.2	6.10	N.S.	5.06	0.0	N.S.	0.0	125	N.S.	129
24	20.1	N.S.	18.3	N.S.	N.S.	8.4	N.S.	7.6	6.07	N.S.	2.96	0.0	N.S.	4.0	123	N.S.	132
29	23.2	N.S.	18.0	N.S.	N.S.	8.4	N.S.	7.3	6.35	N.S.	0.55	0.0	N.S.	12.0	130	N.S.	130
Aug. 6	22.2	N.S.	17.8	N.S.	N.S.	8.4	N.S.	7.3	6.09	N.S.	0.28	0.0	N.S.	12.0	125	N.S.	133
23	19.8	N.S.	18.1	N.S.	N.S.	8.5	N.S.	8.2	6.0	N.S.	5.28	0.0	N.S.	0.0	125	N.S.	129
1927 July 8	19.8	16.6	15.2	15-16	1.2	8.4	7.6	7.4	5.72	3.55	1.53	0.0	5.0	8.0	110	116	123
26	20.5	16.0	15.1	18-21	3.2	8.4	7.3	7.2	5.58	0.0	0.0	0.0	10.0	11.0	112	122	123
Aug. 12	20.0	N.S.	17.8	N.S.	N.S.	8.4	N.S.	7.8	5.44	N.S.	3.90	0.0	N.S.	5.0	113	N.S.	121
1928 June 26	17.6	N.S.	15.6	N.S.	N.S.	8.4	N.S.	7.5									
28	18.0	N.S.	15.9	N.S.	N.S.	8.4	N.S.	7.4	5.79	N.S.	3.49	0.0	N.S.	6.0	112	N.S.	128
July 1	19.4	N.S.	16.0	N.S.	N.S.	8.2	N.S.	7.2	5.72	N.S.	3.35	0.0	N.S.	8.0	111	N.S.	127
24	22.0	18.0	16.5	12-14	3.0	8.1	7.4	7.1	5.00	1.52	0.34	0.0	4.0	9.0	114	120	123
Aug. 7	21.8	N.S.	16.5	N.S.	N.S.	8.2	N.S.	7.2	5.56	N.S.	0.0	0.0	N.S.	10.0	117	N.S.	126
14	22.8	N.S.	16.4	N.S.	N.S.	8.2	N.S.	7.2	5.35	N.S.	0.0	0.0	N.S.	8.0	114	N.S.	126

24 meters

Station 10

TABLE VIII. Seasonal variation of physical-chemical factors.
Sedge Point depression—Douglas Lake.

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923 Aug. 18	20.4	12.5	10.6	12-17	7.4	8.1	7.1	7.1	5.72	0.07	0.0						
1926 July 15	19.9	N.S.	16.3	N.S.	N.S.	8.5	N.S.	7.2	5.91	N.S.	0.0						
July 16	22.0	N.S.	17.2	N.S.	N.S.	8.4	N.S.	7.2	6.27	N.S.	0.0				120	N.S.	131
Aug. 5	22.7	N.S.	17.2	N.S.	N.S.	8.5	N.S.	7.3	5.30	N.S.	0.0				126	N.S.	132
Aug. 27	20.1	N.S.	16.7	N.S.	N.S.	8.6	N.S.	7.6	6.56	N.S.	3.28				122	N.S.	125
1927 July 9	20.0	16.5	12.9	14-16	2.0	8.4	7.6	7.3	5.72	3.21	0.0				116	119	123
Aug. 5	20.1	14.1	13.1	18-20	5.0	8.4	7.4	7.2	5.72	0.0	0.0				118	123	123
Aug. 15	19.9	14.8	14.3	21-22	3.0	8.4	7.3	7.3	5.86	?	0.0				115	122	122
1928 June 27	17.5	N.S.	12.2	N.S.	N.S.	8.4	N.S.	7.1	5.37	N.S.	0.0				110	N.S.	127
July 7	22.1	N.S.	14.6	N.S.	N.S.	8.0	N.S.	7.1	5.72	N.S.	0.03				118	N.S.	125
July 24	22.6	18.3	15.1	12-14	2.1	8.1	7.3	7.1	5.56	1.59	0.0				116	120	125
Aug. 9	22.6	17.0	14.6	15-17	3.0	8.2	7.5	7.1	5.58	2.09	0.0				115	122	125
Aug. 14	24.4	16.4	15.2	16-18	3.2	8.2	7.2	7.0	...	1.18	0.0				...	123	126

Station 20

25 meters

TABLE IX. Seasonal variation of physical-chemical factors.
Fairy Island depression—Douglas Lake.

28 meters

Station 30

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923																	
Aug. 15	20.4	10.3	9.0	14-17	8.0	8.2	7.2	7.0	6.63	0.27	0.0						
1926																	
July 16	19.6	9.7	8.7	18-24	7.7	8.4	7.2	7.2	5.30	0.00	0.0			16.0	126	131	135
28	22.8	13.0	12.0	19-22	3.8	8.4	7.4	7.2	6.48	0.20	0.0	0.0	10.0	18.0	127	N.S.	136
Aug. 6	21.8	N.S.	11.3	N.S.	N.S.	8.4	N.S.	7.3	6.7	N.S.	0.0	0.0	N.S.				
1927																	
July 4	19.7	14.5	12.6	15-18	3.5	8.5	7.4	7.3	5.58	1.95	0.0	0.0	3.0	5.0	114	120	127
16	23.4	15.3	12.6	16-18	2.3	8.4	7.4	7.3	5.44	1.67	0.0	0.0	7.0	11.0	113	119	122
Aug. 10	19.3	13.9	12.8	20-22	4.2	8.4	7.3	7.2	5.23	0.00	0.0	0.0	12.0	13.0	110	121	
1928																	
June 26	17.6	12.2	9.8	21-23	2.6	8.4	7.1	7.0									123
July 1*	19.6	11.8	10.6	20-23	4.2	8.2	7.0	7.0	5.72	0.00	0.0	0.0	10.5	13.0	110	123	
23**	21.7	18.0	11.6	12-13	1.5	8.0	7.5	7.0	5.14	2.84	0.0	0.0	2.0	10.0	112	121	
Aug. 6	21.6	16.4	12.3	15-17	2.1	8.1	7.1	6.9	5.42	0.97	0.0	0.0	5.0	13.0	115	133	130
14***	23.5	16.4	12.5	14-17	3.0	...	7.2	7.0	...	0.00	0.0	...	7.0	12.0	...	124	126

*Values given under u.l.H. for pH, O₂, CO₂, and M.O. Alk. are those recorded at 25 meters, there being no determinations at exactly 23 meters, the exact upper limit of the hypolimnion.
**Values given under u.l.H. for pH, O₂, CO₂, and M.O. Alk. are those recorded at 15 meters.
***Values given under u.l.H. for pH, O₂, CO₂, and M.O. Alk. are those recorded at 20 meters.

TABLE X. *Seasonal variation of physical-chemical factors.*
Stony Point depression—Douglas Lake.

19 meters

Station 40

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S. u.l.H. B.			Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1926																	
July 17	20.0	N.S.	18.0	N.S.	N.S.	8.4	N.S.	7.8	6.09	N.S.	4.95	0.0	N.S.	10.0	125	N.S.	130
Aug. 16	21.2	N.S.	18.0	N.S.	N.S.	8.5	N.S.	7.4	6.28	N.S.	0.48	0.0	N.S.	10.0	122	N.S.	129
Aug. 27	20.2	N.S.	18.0	N.S.	N.S.	8.6	N.S.	7.4	6.49	N.S.	0.06	0.0	N.S.	10.0	116	N.S.	120
1927																	
July 9	20.0	N.S.	16.0	N.S.	N.S.	8.4	N.S.	7.6	5.72	N.S.	3.07	0.0	N.S.	5.0	111	N.S.	121
July 25	20.8	N.S.	19.2	N.S.	N.S.	8.4	N.S.	7.8	4.88	N.S.	2.96	0.0	N.S.	4.0	117	N.S.	122
Aug. 15	19.9	N.S.	19.0	N.S.	N.S.	8.4	N.S.	8.0	5.79	N.S.	4.60	0.0	N.S.	0.5	113	N.S.	127
1928																	
June 28	18.1	N.S.	16.0	N.S.	N.S.	8.4	N.S.	7.3	5.58	N.S.	2.93	0.0	N.S.	9.0	118	N.S.	125
July 16	21.0	17.2	17.4	12-15	3.0	8.0	7.4	7.2	5.51	1.74	1.53	0.0	6.0	10.0	114	120	127
July 25	22.6	18.6	16.4	13-14	1.4	8.1	7.3	7.2	5.56	1.52	0.0	0.0	5.0	9.0	117	N.S.	126
Aug. 7	22.5	N.S.	19.1	N.S.	N.S.	8.2	N.S.	7.5	5.62	N.S.	2.29	0.0	N.S.	5.0	...	N.S.	125
Aug. 14	24.8	N.S.	17.8	N.S.	N.S.	8.2	N.S.	7.3	...	N.S.	0.34	0.0	N.S.	9.0	...	N.S.	125

TABLE XI. Seasonal variation of physical-chemical factors.
Roberts Point depression—Douglas Lake.

Station 50	Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.			23 meters
		S.		B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	
		S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	
1926																			
	July 23	21.9	18.6	14.4	11-12	1.2	8.4	8.3	7.2	6.27		0.03	0.0	1.0	15.0	125			
	Aug. 3	24.4	N.S.	15.3	N.S.	N.S.	8.5	N.S.	7.2	6.28	N.S.	0.00	0.0	N.S.	16.0	125			
	Aug. 11	21.2	N.S.	14.2	N.S.	N.S.	8.6	N.S.	7.2	6.49	N.S.	0.00	0.0	N.S.	16.0	124			
	Aug. 16	21.5	N.S.	14.0	N.S.	N.S.	8.5	N.S.	7.2	6.35	N.S.	0.00	0.0	N.S.	16.0	124			
1927																			
	July 5	20.0	13.7	12.2	14-16	4.3	8.4	7.5	7.3	5.72	2.51	0.83	0.0	4.0	6.0	113			
	Aug. 18	21.0	13.5	12.5	14-17	5.4	8.4	7.4	7.3	5.30	1.18	0.69	0.0	7.0	10.0	114			
	Aug. 12	19.6	14.4	13.0	17-19	3.8	8.4	7.4	7.3	5.51	0.00	0.00	0.0	10.1	25.0	113			
1928																			
	June 26	17.5	13.4	13.7	17-18	1.4	8.4	7.3	7.2				0.0	6.0	10.0	116			
	July 5	20.8	14.5	12.6	16-17	1.1	8.2	7.3	7.1	5.57	0.22	0.00	0.0	3.0	10.0	118			
	July 12	20.8	17.8	12.5	10-11	2.4	8.1	7.5	7.1	5.44	3.55	0.00	0.0	3.0	10.0	113			
	Aug. 25	23.0	16.5	13.0	11-14	4.5	8.1	7.2	7.1	5.62	1.73	0.00	0.0	3.0	13.0	115			
	Aug. 6	22.4	13.9	13.0	13-18	5.6	8.1	7.1	7.0	5.49	0.00	0.00	0.0	9.0	12.0	114			
	Aug. 14	23.7	15.1	13.2	14-16	3.2	8.1	7.3	7.0		0.00	0.00	0.0	5.0	11.0	121			
	Oct. 20	11.1	N.S.	11.1	N.S.	N.S.	7.8	N.S.	7.8	7.10	N.S.	6.48	1.5	N.S.	1.5	163			

TABLE XII. Seasonal variation of physical-chemical factors, Third Sister Lake.

18 meters

Station 1

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923														
Feb. 17	0.1	...	5.0											
Feb. 28	0.5	...	4.75											
Apr. 25	...	...	6.5	1-7	6.8	7.8	7.6	7.4						
May 2	14.9	7.6	4.7	3-7	6.5	8.4	7.8	7.4						
1926														
Oct. 19	12.7	...	...	...	...	7.4	...	...	6.1					
Oct. 20	12.2	8.2	6.5	8-10	4.2	7.4	7.1	7.0	6.28	0.34	0.0	2.0	9.0	13.0
Oct. 26	9.7	7.5	6.5	11-12	1.0	7.4	7.1	7.0	6.20	0.00	0.0	2.0	9.0	12.0
Nov. 2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Nov. 10	8.1	N.S.	6.6	N.S.	N.S.	7.4	N.S.	7.4	6.1	N.S.	0.0	2.0	N.S.	12.0
Nov. 17	5.6	N.S.	6.8	N.S.	N.S.	7.4	N.S.	7.4	5.72	N.S.	5.72	2.0	N.S.	3.5
Nov. 17	6.5	N.S.	6.0	N.S.	N.S.	7.4	N.S.	7.4	5.75	N.S.	6.18	3.0	N.S.	3.5
Nov. 24	3.8	N.S.	4.0	N.S.	N.S.	7.5	N.S.	7.5	5.81	N.S.	6.2	3.0	N.S.	3.0
1927														
Jan. 5	0.9	...	4.2	...	...	7.6	...	7.0	6.65	...	2.17	5.0	...	11.0
Apr. 16	8.0	N.S.	6.4	N.S.	N.S.	8.0	N.S.	7.4	7.24	...	5.46	1.5	N.S.	8.0
June 9	18.2	8.0	6.9	5-10	7.6	8.0	7.2	7.1	6.53	4.73	0.00	1.0	7.0	13.0
Aug. 9	18.4	8.1	6.8	4-10	8.1	7.9	7.3	7.0	6.38	5.32	0.00	1.5	5.5	12.5
Aug. 27	21.3	9.3	7.7	5-11	10.8	8.4	7.0	7.0	5.71	0.00	0.00	0.0	8.0	13.0
Sept. 13	23.6	9.0	7.3	5-9	11.2	8.4	7.0	6.9	5.31	0.76	0.00	0.0	8.0	10.0
Sept. 15	24.1	9.1	7.3	5-9	10.9	8.4	7.0	7.0	5.37	0.06	0.00	0.0	7.0	10.0
Sept. 16	24.5	9.2	7.4	5-9	10.8	...	...	...	...	...	...	...	...	...
Sept. 17	25.5	9.0	7.4	4-10	13.5	8.4	7.0	7.0	5.44	0.05	0.00	0.0	7.0	15.0
Sept. 27	18.2	7.8	7.3	6-12	9.7	7.8	7.0	6.9	5.50	0.00	0.00	1.0	6.0	17.0
Oct. 4	18.0	8.8	7.2	6-10	8.5	7.8	7.0	6.9	5.45	0.00	0.00	1.5	5.0	18.0
Oct. 11	15.8	9.1	7.2	7-10	6.2	7.7	7.0	6.8	5.58	0.00	0.00	2.2	5.0	18.0
Oct. 18	12.8	8.3	7.2	9-11	4.2	7.6	7.0	6.8	5.79	0.13	0.00	3.0	5.0	20.0

TABLE XII. (Continued)
Seasonal variation of physical-chemical factors. Third Sister Lake. 18 meters

Station 1	Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.		
		S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
	1927														
	Oct. 25	13.0	8.3	7.3	9-11	4.1	7.7	7.0	6.8	5.86	0.13	0.0	3.0	6.0	22.0
	Nov. 1	13.8	8.4	7.3	9-11	2.9	7.8	7.0	6.8	5.62	0.00	0.0	2.5	7.0	25.0
	8	9.0	8.1	7.4	12-13	1.0	7.6	7.3	7.0	5.55	0.61	0.06	3.0	5.0	15.0
	15	9.2	N.S.	7.4	N.S.	N.S.	7.6	N.S.	7.0	5.44	N.S.	0.06	3.0	N.S.	15.0
	22	6.7	N.S.	6.6	N.S.	N.S.	7.4	N.S.	7.3	5.0	N.S.	4.61	5.0	N.S.	5.0
	26	7.0	N.S.	6.8	N.S.	N.S.	7.5	N.S.	7.5	4.96	N.S.	4.76	5.0	N.S.	5.0
	29	7.2	N.S.	7.2	N.S.	N.S.	7.6	N.S.	7.5	5.67	N.S.	5.3	4.0	N.S.	5.0
	Dec. 6	4.6	N.S.	4.8	N.S.	N.S.	7.7	N.S.	7.6	5.56	N.S.	5.31	3.0	N.S.	4.0
	1928														
	Jan. 23	1.0	N.S.	2.8	N.S.	N.S.	8.0	N.S.	7.7	6.52	N.S.	4.43	2.0	N.S.	4.0
	Feb. 22	0.5	...	3.0	...	...	7.6	...	7.4	5.73	...	3.69	3.0	...	5.0
	Apr. 6	10.3	5.5	4.8	5-7	2.0	7.8	7.6	7.5	5.27	6.0	5.03			
	20	8.6	N.S.	6.2	N.S.	N.S.	7.8	N.S.	7.7	4.05	N.S.	4.98			
	May 23	20.0	10.1	6.5	1-6	9.9	8.0	7.8	7.7	4.36	6.57	2.21	0.5	1.0	11.0
	June 6	15.0	8.3	6.5	5-9	6.3	8.0	7.4	7.0	4.99	3.59	0.12	2.0	3.0	10.0
	Oct. 10	14.8	9.6	7.6	5-9	4.9	7.5	6.6	6.5	6.00	0.00	0.00	1.5	5.0	9.0
	Nov. 3	11.4	8.0	7.6	11-12	1.3	7.3	6.7	6.5	5.65	0.50	0.00			
	10	8.6	N.S.	7.7	N.S.	N.S.	7.5	N.S.	6.9	4.74	N.S.	0.01	3.0	N.S.	12.0
	24	4.7	N.S.	4.6	N.S.	N.S.	7.3	N.S.	7.3	7.04	N.S.	3.76	1.0	N.S.	2.0
	Dec. 15	1.4	N.S.	4.2	N.S.	N.S.	7.2	N.S.	7.2	8.45	N.S.	2.6	2.5	N.S.	3.0
	1929														
	Feb. 9	0.5	...	4.0	...	...	7.2	...	6.9	8.18	...	1.83	1.0	...	3.0

TABLE XIII. *Vertical temperature series. Green Lake—Kirkville, New York, 1925.*

Depth Meters	April 13	April 15	May 9	June 17	June 18	June 22	June 26	June 27	June 28
0.....	8.8	7.8	12.1	22.4	22.8	24.0	21.3	22.5	23.9
0.5....	...	...	...	...	...	...	21.1		
1.....	...	7.8	11.7	20.8	21.1	22.1	20.8		
2.....	...	7.8	11.7	20.7	20.8	21.0	20.5		
3.....	...	7.8	10.8	20.7	20.6	20.4	20.3		
4.....	...	6.7	10.6	18.9	19.0	19.3	19.3		
5.....	7.1	6.2	10.4	15.8	15.8	18.0	18.3		
6.....	...	6.1	...	14.2	14.1	16.6	17.3		
7.....	...	6.1	...	12.5	12.4	14.1	16.3		
8.....	...	6.1	...	11.7	11.6	12.8	15.6		
9.....	...	5.9	...	10.4	10.5	12.1	15.0		
10.....	5.8	5.9	9.1	9.5	9.6	11.1	14.9	14.8	14.9
11.....	...	5.7	7.9	...	8.9	10.2			
12.....	...	5.5	6.1	...	8.2	10.1	11.8		
13.....	...	5.2	5.4	...	7.5	8.5			
14.....	...	5.0	5.4	...	6.3	6.8	7.3		
15.....	4.8	4.8	4.8	5.6	5.6	5.6	5.6		
16.....	...	4.7	5.0	4.8	4.7	4.5	4.6		
17.....	...	4.7	5.6	5.7	4.8	5.1	5.1		
18.....	...	4.6	6.3	6.2	5.4	5.6	5.8		
19.....	...	4.4	6.6	7.0	6.1	...	6.7		
20.....	4.4	4.4	7.2	7.1	7.1	7.0	7.0	7.0	7.0
21.....	...	...	...	...	...	...	7.0		
22.....	...	...	...	...	...	...	7.0		
25.....	4.4	4.4	7.2	8.2	8.2	7.2	7.1		
30.....	4.7	4.7	7.2	7.9	8.1	7.4	7.7	7.3	7.3
35.....	4.8	4.8	7.2	7.9	8.1	7.5	7.4		
40.....	4.9	4.9	7.3	7.6	7.6	7.3	7.5	7.5	7.5
45.....	5.0	5.1	7.3	7.6	7.6	7.5	7.5		
50.....	5.0	5.1	7.4	7.7	7.8	7.8	7.6	7.6	7.7
55.....	5.0	5.2	...	7.8	7.8	8.0	7.8		
57.....	...	...	7.7						
58.....	...	...	...	7.9					
59.....	...	...	...	...	7.9	8.0	8.1		
59.5....	...	...	...	...	...	...	8.1		
60.....	5.1	5.3	...	...	...	...	...	8.1	8.1
61.....	...	5.6	...	...	...	...	...	...	8.2

Temperatures expressed in degrees Centigrade.

TABLE XIV. *Seasonal variation of bottom fauna. South Fish-Tail Depression—
Douglas Lake.*

Station 1

21-24 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1923							
July 5	10	267	31	0	0	0	298
11	30	149	26	0	0	0	175
16	12	93	34	0	0	0	127
20	10	103	58	0	0	0	161
21	13	86	41	0	0	0	127
Aug. 1	6	23	0	0	0	0	23
10	23	4	0	0	0	0	4
18	3	30	15	0	45	0	90
1926							
June 19	2	334	0	0	0	0	334
30	10	138	40	23	9	0	210
July 2	5	98	27	45	27	0	197
7	15	131	27	21	60	3	242
22	10	58	23	0	23	0	104
28	40	87	66	0	30	0	183
Aug. 9	10	5	0	5	14	0	24
10	10	5	9	0	5	0	19
11	5	6	8	0	4	0	18
13	10	45	14	5	9	0	73
26	10	147	0	0	54	0	201
1927							
June 24	10	187	36	32	23	0	278
July 2	5	178	27	27	9	0	241
20	35	55	16	8	8	0	87
25	10	49	5	5	14	0	73
28	25	38	15	0	2	0	55
Aug. 15	5	36	18	0	10	0	64
1928							
June 22	2	289	0	0	0	0	289
27	5	303	0	0	10	0	313
July 2	10	316	14	5	9	0	344
9	15	305	12	6	18	0	341
19	10	200	18	9	40	0	267
30	10	10	5	0	9	0	24
Aug. 2	5	27	18	0	9	0	54
12	15	39	3	0	18	0	60
Oct. 20	5	3,448	80	36	18	0	3,582
Total.....	401						

TABLE XV. *Seasonal variation of bottom fauna. Sedge Point depression—Douglas Lake. Station 20* 21-24 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1923							
Aug. 18	15	24	12	0	0	0	36
1926							
July 15	10	726	9	116	5	5	931
26	10	489	0	49	14	0	552
Aug. 5	25	4	0	0	10	0	14
27	15	274	0	9	15	0	298
1927							
July 9	10	1,098	58	23	32	0	1,211
23	10	698	49	32	40	0	819
Aug. 5	5	80	125	0	27	0	232
15	5	45	45	0	0	0	90
1928							
June 28	2	3,355	45	45	0	0	3,445
July 7	5	898	9	36	0	0	943
8	2	867	0	44	0	0	911
24	10	18	0	0	14	0	32
Aug. 9	10	63	14	0	23	0	100
Total.....	134						

TABLE XVI. *Seasonal variation of bottom fauna. Fairy Island depression—Douglas Lake. Station 30* 21-28 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1923							
Aug. 15	30	5	3	0	26	0	34
1926							
July 16	10	303	63	5	18	0	389
28	10	156	14	5	32	0	207
Aug. 6	15	69	63	3	72	0	207
1927							
July 4	10	94	27	0	54	0	175
16	10	40	27	5	45	0	117
Aug. 10	10	9	63	0	45	0	117
1928							
July 1	2	43	7	0	23	0	73
23	10	36	76	0	49	0	161
Aug. 6	5	27	18	0	45	0	90
Total.....	112						

TABLE XVII. *Seasonal variation of bottom fauna. Roberts Point depression—Douglas Lake.*

Station 50

21-22 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
July 14	15	503	37	14	31	0	585
23	10	391	14	9	49	0	463
Aug. 3	10	58	18	0	23	0	99
11	12	23	0	0	49	0	72
16	10	63	18	23	67	0	171
1927							
July 5	5	196	356	151	0	0	703
18	5	169	400	89	0	0	658
Aug. 12	10	129	85	0	129	0	343
1928							
July 5	5	640	36	18	116	0	810
12	5	223	89	54	98	0	464
25	5	45	89	27	45	0	206
Aug. 6	25	63	36	18	11	8	136
10	46	151	42	11	126	10	340
Oct. 20	4	2,278	144	112	67	156	2,757
Total.....	167						

TABLE XVIII. *Seasonal variation of bottom fauna. Stony Point depression—Douglas Lake.*

Station 40

17-19 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
July 17	10	67	14	254	63	174	572
Aug. 16	10	54	18	14	63	49	198
27	5	738	18	63	89	45	953
1927							
July 9	5	116	72	9	18	9	224
25	5	54	98	27	0	27	206
Aug. 5	15	9	18	5	9	9	50
15	5	72	240	0	27	0	339
1928							
June 28	2	1,334	245	445	156	89	2,269
July 16	5	18	54	98	45	89	304
25	10	67	129	40	45	49	330
Aug. 7	5	89	116	45	45	63	358
Total.....	77						

TABLE XIX. *Seasonal variation of bottom fauna. Grapevine Point depression.*
Station 10 *21-25 meters*

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1923							
Aug. 18	6	52	15	0	0	0	67
1926							
July 14	10	1,049	14	80	5	0	1,148
24	10	191	14	360	27	14	606
29	10	343	23	190	40	23	619
Aug. 6	15	12	3	63	6	0	99
23	10	809	23	5	14	5	856
1927							
July 8	25	310	249	247	29	9	844
26	10	18	125	5	9	18	175
Aug. 12	5	267	27	18	9	0	321
1928							
June 28	5	2,302	214	525	80	0	3,121
July 24	5	18	134	89	116	36	393
Aug. 7	5	240	151	9	63	18	481
Total.....	116						

TABLE XX. Seasonal variation of bottom fauna. Center of Third Sister Lake.
Station 1 18 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Oct. 20	5	5,866	27	0	151	0	6,044
26	5	7,529	0	0	196	0	7,725
Nov. 2	6	12,665	0	0	171	0	12,836
10	2	28,798	311	156	423	0	29,688
17	2	32,108	423	200	734	0	33,465
24	2	35,130	334	178	645	0	36,287
1927							
Jan. 5	5	41,730	36	9	80	0	41,855
Apr. 16	3	34,391	164	45	30	60	34,690
June 1	5	5,751	54	98	80	0	5,983
9	2	7,354	67	112	89	0	7,622
Aug. 27	5	1,520	116	63	196	0	1,895
Sept. 13	5	3,049	27	72	125	0	3,273
15	5	2,018	27	0	169	0	2,214
16	5	2,748	63	26	196	0	3,033
17	5	2,871	28	0	152	0	3,051
27	5	3,564	0	0	89	0	3,653
Oct. 4	5	3,476	0	0	285	0	3,761
11	5	3,333	0	0	311	0	3,644
18	5	6,915	0	0	320	0	7,235
Nov. 1	5	7,057	0	0	303	0	7,360
8	2	15,910	0	0	312	0	16,222
15	2	21,265	0	0	423	23	21,711
21	5	37,179	71	0	418	107	37,775
26	5	34,717	89	0	489	89	35,384
29	1	36,489	623	0	534	89	37,735
Dec. 6	1	47,818	1,023	0	312	89	49,242
1928							
Jan. 23	2	71,526	45	0	67	0	71,638
Feb. 22	1	68,705	0	0	45	0	68,750
Apr. 7	4	41,119	12	0	23	12	41,166
11	4	36,497	12	12	23	12	36,556
*25	25	9,251	294	13	*1,550	18	11,126
June 6	2	6,710	445	67	89	0	7,311
Oct. 10	5	2,694	0	0	151	0	2,845
Nov. 10	5	4,764	27	0	125	0	4,916
24	5	28,380	1,876	89	285	18	30,648
Dec. 15	5	57,372	2,399	70	223	89	60,153
1929							
Feb. 9	2	68,038	956	0	289	0	69,283
Total	163						

*Samples taken on this date from 16, 17, and 18 meters were combined.

TABLE XXI. *Seasonal distribution of bottom fauna. Third Sister Lake.*
Station 2 16-17 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chironomus	Proten-thes	Tubi-ficidae	All Others	
1926							
Nov. 17	2	29,397	578	245	1,645	45	31,910
24	2	29,953	511	156	1,845	23	32,488
1927							
Sept. 27	5	1,120	18	0	1,813	0	2,950
Oct. 11	5	3,715	27	0	471	0	4,213
Nov. 8	2	13,444	0	0	689	0	14,133
15	2	21,576	23	0	578	45	22,222
22	4	23,542	256	0	978	89	24,865
26	4	26,042	400	12	1,145	90	27,690
1928							
Jan. 23	2	48,373	112	0	845	0	49,330
Feb. 22	1	53,595	90	0	623	0	54,308
Total.....	29						

TABLE XXII. *Seasonal distribution of bottom fauna. Third Sister Lake.*
Station 3 14-15 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chironomus	Proten-thes	Tubi-ficidae	All Others	
1927							
Nov. 8	2	13,288	0	0	2,644	0	15,932
15	3	17,707	90	0	2,580	90	20,467
22	5	10,400	356	9	7,377	98	18,240
26	4	9,077	356	34	8,933	78	18,478
Dec. 6	2	11,158	911	45	9,400	0	21,514
1928							
Jan. 23	3	9,150	1,024	45	8,646	0	18,865
Feb. 22	1	9,866	845	45	9,200	0	19,956
Apr. 11	3	8,157	341	45	6,792	45	15,380
June 6	2	4,888	312	134	4,466	0	9,800
Oct. 10	2	11,266	0	0	267	0	11,533
Nov. 10	2	14,176	911	267	2,710	445	18,510
1929							
Feb. 9	2	37,996	711	23	245	24	39,000
Total.....	31						

TABLE XXIII. Seasonal distribution of bottom fauna. Third Sister Lake.
Station 4 11.5-13 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Nov. 2	2	15,620	200	67	9,644	45	25,576
10	2	3,045	2,090	645	6,690	200	12,670
1927							
Oct. 11	3	3,100	30	0	3,650	89	6,869
Nov. 8	2	13,910	67	23	13,310	23	27,333
15	2	3,555	533	0	11,666	134	15,888
22	3	2,314	1,780	149	12,770	134	17,147
26	3	2,536	1,424	89	9,180	208	13,437
1928							
Jan. 23	7	139	1,816	242	8,418	235	10,850
Feb. 22	10	116	1,960	147	11,137	120	13,480
Apr. 11	4	523	1,322	456	18,132	100	20,533
June 6	2	2,022	2,510	178	11,577	89	16,376
Oct. 10	4	4,400	0	0	3,233	0	7,633
Nov. 10	2	15,345	822	134	10,510	23	26,834
1929							
Feb. 9	2	1,245	3,644	0	16,020	67	20,976
Total	48						

TABLE XXIV. Seasonal distribution of bottom fauna. Third Sister Lake.
Station 5 9-10 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Nov. 10	2	2,600	4,355	867	5,133	578	13,533
1927							
Sept. 27	1	489	1,733	0	1,510	0	3,732
Oct. 11	3	757	920	0	149	282	2,108
Nov. 8	2	445	3,777	311	5,510	267	10,310
15	8	383	3,083	428	6,789	322	11,005
22	3	504	2,269	223	7,786	178	11,960
26	3	564	1,558	163	7,964	119	10,368
Dec. 6	1	667	933	134	7,066	311	9,111
1928							
Jan. 23	2	45	134	67	5,289	845	6,380
Feb. 22	1	89	178	89	5,422	1,022	6,800
Apr. 11	3	727	1,810	742	14,489	312	18,080
June 6	2	2,910	689	1,645	7,466	111	12,821
Oct. 10	2	2,933	178	0	3,844	0	6,955
Nov. 10	2	2,422	5,800	911	4,800	445	14,378
1929							
Feb. 9	2	0	1,800	134	8,022	311	10,267
Total	37						

TABLE XXV. *Seasonal distribution of bottom fauna, Third Sister Lake.*
Station 6 *7-8 meters*

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Nov. 17	2	89	3,156	200	2,733	778	6,956
1927							
June 9	4	511	767	2,078	12,177	323	15,856
Sept. 27	5	4,204	6,142	507	1,254	1,369	13,476
Oct. 11	5	3,600	6,969	480	1,111	1,307	13,467
Oct. 18	2	1,555	4,400	845	1,378	200	8,378
25	5	311	4,595	791	2,044	676	8,417
Nov. 1	3	134	4,450	519	1,083	727	6,913
8	2	45	3,155	267	2,822	800	7,089
15	2	45	667	489	3,422	800	5,423
22	2	134	178	267	7,555	2,533	10,667
26	3	75	238	193	5,695	682	6,883
Dec. 6	2	0	156	311	4,577	712	5,756
1928							
Feb. 22	5	0	80	276	4,524	605	5,485
Apr. 11	3	225	2,848	2,195	5,962	1,757	12,987
June 6	2	445	734	2,755	16,598	289	20,821
Oct. 10	4	3,522	5,322	1,144	1,166	433	11,587
Nov. 10	4	234	1,056	645	1,900	4,010	7,845
1929							
Feb. 9	2	0	45	689	16,000	1,800	18,534
Total.....	57						

TABLE XXVI. Seasonal distribution of bottom fauna. Third Sister Lake.
Station 7 5-6 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Nov. 10	5	0	0	36	27	320	383
17	5	0	9	27	18	187	241
24	2	200	45	23	0	67	335
1927							
Sept. 27	10	631	151	23	143	462	1,410
Oct. 11	4	467	178	34	300	722	1,701
Nov. 8	2	67	156	445	400	1,244	2,312
15	1	134	223	667	45	978	2,047
1928							
Nov. 10	2	23	89	400	134	1,378	2,024
Total.....	31						

TABLE XXVII. Seasonal distribution of bottom fauna. Third Sister Lake.
Station 8 3-4 meters

Date	No. of Samples	Number per square meter					Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	All Others	
1926							
Nov. 17	2	0	45	112	0	145	802
24	1	0	45	134	0	267	446
1928							
Oct. 10	2	0	45	267	289	889	1,490
Nov. 10	2	0	0	67	200	178	445
Total.....	7						

TABLE XXVIII. *Depth distribution of bottom fauna. Third Sister Lake.*

Date	Depth meters	Number per square meter						Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	Hydra- carina	All Others	
1926								
Nov. 10	5-6	0	0	36	27	80	240	383
	9-10	2,600	4,355	867	5,133	511	67	13,533
	11.5-13	3,045	2,090	645	6,690	0	200	12,670
	18	28,798	311	156	423	0	0	29,688
Nov. 17	3-4	0	45	112	0	0	645	802
	5-6	0	9	27	18	56	133	241
	7-8	89	3,156	200	2,733	400	378	6,956
	16-17	29,397	578	245	1,645	0	45	31,910
	18	32,108	423	200	734	0	0	33,456
Nov. 24	3-4	0	45	134	0	0	267	446
	5-6	200	45	23	0	0	67	335
	16-17	29,953	511	156	1,845	0	23	32,488
	18	35,130	334	178	645	0	0	36,287
1927								
Sept. 27	5-6	631	151	23	143	107	355	1,410
	7-8	4,204	6,142	507	1,254	649	720	13,476
	9-10	489	1,733	0	1,510	0	0	3,732
	16-17	1,120	18	0	1,813	0	0	2,950
	18	3,564	0	0	89	0	0	3,653
Oct. 11	5-6	467	178	34	300	12	710	1,701
	7-8	3,600	6,969	480	1,111	711	596	13,467
	9-10	757	920	0	149	0	282	2,108
	11.5-13	3,100	30	0	3,650	60	29	6,869
	16-17	3,715	27	0	471	0	0	4,213
	18	3,333	0	0	311	0	0	3,644
Nov. 8	5-6	67	156	445	400	200	1,044	2,312
	7-8	45	3,155	267	2,822	400	400	7,089
	9-10	445	3,777	311	5,510	267	0	10,310
	11.5-13	13,910	67	23	13,310	23	0	27,333
	14-15	13,288	0	0	2,644	0	0	15,932
	16-17	13,444	0	0	689	0	0	14,133
	18	15,910	0	0	312	0	0	16,222
Nov. 15	5-6	134	223	667	45	667	311	2,047
	7-8	45	667	489	3,422	578	222	5,423
	9-10	383	3,083	428	6,789	311	11	11,005
	11.5-13	3,555	533	0	11,666	134	0	15,888
	14-15	17,707	90	0	2,580	90	0	20,467
	16-17	21,576	23	0	578	45	0	22,222
	18	21,265	0	0	423	23	0	21,711
Nov. 26	7-8	75	238	193	5,695	0	682	6,883
	9-10	564	1,558	163	7,964	119	0	10,368
	11.5-13	2,536	1,424	89	9,180	208	0	13,437
	14-15	9,077	356	34	8,933	78	0	18,478
	16-17	26,042	400	12	1,145	90	0	27,690
	18	34,717	89	0	489	89	0	35,384
Dec. 6	7-8	0	156	311	4,577	0	712	5,756
	9-10	667	933	134	7,066	311	0	9,111
	14-15	11,158	911	45	9,400	0	0	21,514
	18	47,818	1,023	0	312	89	0	49,242

TABLE XXVIII. (Continued)

Date	Depth meters	Number per square meter						Totals
		Corethra	Chiron- omus	Proten- thes	Tubi- ficidae	Hydra- carina	All Others	
1928								
Feb. 22	7-8	0	80	276	4,524	0	605	5,485
	9-10	89	178	89	5,422	400	622	6,800
	11.5-13	116	1,960	147	11,137	112	8	13,480
	14-15	9,866	845	45	9,200	0	0	19,956
	16-17	53,595	90	0	623	0	0	54,308
	18	68,705	0	0	45	0	0	68,750
Apr. 11	7-8	225	2,848	2,195	5,962	697	1,060	12,987
	9-10	727	1,810	742	14,489	225	87	18,080
	11.5-13	523	1,322	456	18,132	89	11	20,533
	14-15	8,157	341	45	6,792	45	0	15,380
	18	36,497	12	12	23	12	0	36,556
June 6	7-8	445	734	2,755	16,598	23	266	20,821
	9-10	2,910	689	1,645	7,466	111	0	12,821
	11.5-13	2,022	2,510	178	11,577	67	22	16,376
	14-15	4,888	312	134	4,466	0	0	9,800
	18	6,710	445	67	89	0	0	7,311
Oct. 10	3-4	0	45	267	289	134	755	1,490
	7-8	3,522	5,322	1,144	1,166	211	222	11,587
	9-10	2,933	178	0	3,844	0	0	6,955
	11.5-13	4,400	0	0	3,233	0	0	7,633
	14-15	11,266	0	0	267	0	0	11,533
	18	2,694	0	0	151	0	0	2,845
Nov. 10	3-4	0	0	67	200	89	89	445
	5-6	23	89	400	134	111	1,267	2,024
	7-8	234	1,056	645	1,900	345	3,665	7,845
	9-10	2,422	5,800	911	4,800	356	89	14,378
	11.5-13	15,345	822	134	10,510	0	23	26,834
	14-15	14,176	911	267	2,710	45	400	18,510
	18	4,764	27	0	125	0	0	4,916
1929								
Feb. 9	7-8	0	45	689	16,000	311	1,489	18,534
	9-10	0	1,800	134	8,022	245	66	10,267
	11.5-13	1,245	3,644	0	16,020	45	22	20,976
	14-15	37,996	711	23	245	24	0	39,000
	18	68,038	956	0	289	0	0	69,283

TABLE XXIX. *Depth distribution of bottom fauna, Douglas Lake.*

Locality	Date	Depth meters	No. Samples	Number per square meter							Totals
				Corethra	Chiron- omus	Proten- thes	Tubifi- cidae	Sphaeri- idae	Nematoda	All Others	
Grapevine Channel.....	1926 June 25	13	5	0	9	9	0	0	0	0	18
		15	5	258	89	205	400	0	9	0	961
		16	5	231	116	347	27	0	0	0	721
	28	12	10	0	23	9	0	0	0	0	32
		13	10	5	40	18	0	0	58	0	121
South Fish-Tail Dep.....	July 7	14	10	227	302	307	9	27	573	40	1,485
		15	5	98	125	205	45	0	178	0	651
		14	1	134	0	89	45	0	0	0	268
		17	1	45	0	45	45	0	0	0	135
		18	1	90	45	0	0	0	0	0	135
	Aug. 10	21	1	0	0	0	0	0	0	0	0
		23	15	131	27	21	60	0	0	3	242
		15	5	0	71	18	0	0	0	0	89
		17	5	54	62	107	36	0	0	0	259
		18	10	36	9	45	40	0	0	0	130
South Fish-Tail Dep.....	1928 June 22	22	5	9	9	10	0	0	0	28	
		23	10	5	9	0	5	0	0	0	19
		12	1	45	194	489	178	45	266	89	1,306
		18	2	800	67	1,000	89	0	0	45	2,001
		4-8	20	0	0	0	0	0	0	0	0
North Fish-Tail Bay.....	July 2	10	5	27	160	107	160	54	0	578	1,086
		10.5	5	116	18	53	169	36	0	418	810
		11	5	54	89	418	151	18	0	72	802
		12	2	356	90	289	45	45	23	0	848

TABLE XXIX. (Continued)
Depth distribution of bottom fauna, Douglas Lake.

Locality	Date	Depth meters	No. Samples	Number per square meter						All Others	Totals
				Corethra	Chiron- omus	Proten- thes	Tubifi- cidae	Sphaeri- idae	Nematoda		
Roberts Point Dep.....	July 12	10	5	0	36	10	80	0	0	0	126
		15	5	382	651	229	0	134	0	125	1,521
		20	5	391	116	187	18	0	9	27	748
		21	5	222	89	34	98	0	0	0	443
		22	5	223	89	54	98	0	0	0	464
Fairy Island Dep.....	July 23	17	5	418	223	142	62	18	0	9	872
		20	5	142	151	10	240	0	0	0	543
		23	5	54	106	0	80	0	0	0	240
		28	5	18	45	0	18	0	0	0	81
Grapevine Channel.....	Aug. 4	10	5	0	0	0	0	0	0	0	0
		11	5	0	0	0	0	0	0	0	0
		15	5	0	0	0	0	0	0	0	0
		13	5	98	125	187	0	0	409	18	837
		14	4	56	167	522	45	0	189	11	990
South Fish-Tail Bay.....	Aug. 4	15	5	90	134	169	89	0	782	36	1,300
		10.5	5	0	36	9	18	0	0	36	99
		12	5	89	445	89	267	0	0	0	890
		13	5	45	445	356	329	27	0	54	1,256
		15	5	275	54	54	134	0	0	0	517
Roberts Point Dep.....	Aug. 6	18	5	160	62	45	152	9	0	0	428
		20	5	45	36	0	10	0	0	0	91
		23	5	27	18	0	9	0	0	0	54
		10	5	18	36	98	0	45	0	98	295
		11	5	143	45	27	36	0	0	63	314
		13	5	340	276	71	18	0	0	0	705
		20	5	187	258	36	178	0	0	0	659
		22	25	63	36	18	11	0	0	8	136

TABLE XXX. Occurrence of bottom fauna. Douglas Lake.

Locality	Date	Depth meters	No. Samples	Number per square meter						Totals
				Corethra	Chiron- omus	Proten- thes	Tubifi- cidae	Hydra- carina	Sphaeri- idae	
Maple Point Dep.....	1923 Aug. 18 1926	16	15	0	0	0	0	0	0	0
Grapevine Channel.....	June 21 July 12 Aug. 3	17 15 17	2 5 5	422 169 178	245 80 45	334 80 27	0 27 18	0 0 0	67 10 9	112 0 10
Roberts Point Dep.....	Aug. 3	17	5	63	231	36	230	10	5	27
N. F. T. Bay, Sta. 70.....	Aug. 20	11	10	205	98	0	143	9	0	160
N. F. T. Bay, Sta. 60.....	Aug. 20 1927	11	10							
Midway between Stations 30 and 50.....	Aug. 10	17	5	107	223	125	0	0	10	18

TABLE XXXI. Summary of bottom samples. Green Lake, Kirkeville, New York.

1-61 meters

Date	Depth meters	No. Samples	Number per square meter										Remarks	
			Cor.	Chir.	Prot.	Tub.	Hydra- carina	Suc.	Phy.	Val.	Gon.	Plan.		All Others
June 17	21	5	0	0	0	0	0	0	0	0	0	0	0	Very black mud—H ₂ S
17	55-61	13	0	0	0	0	0	0	0	0	0	0	0	Much H ₂ S
18	5	5	0	0	0	0	0	0	0	27	0	240	0	Much gray marl
22	1	2	0	0	0	0	45	23	67	45	134	112	1,066	Much gray marl
26	3	2	0	0	0	0	112	0	0	0	23	178	134	
26	58	13	0	0	0	0	0	0	0	0	0	0	0	
27	4-8	15	0	0	0	0	0	0	0	0	0	0	0	Gray marl to black mud
27	10-30	15	0	0	0	0	0	0	0	0	0	0	0	Black mud—H ₂ S
27	40-61	35	0	0	0	0	0	0	0	0	0	0	0	H ₂ S very strong
28	60-30	25	0	0	0	0	0	0	0	0	0	0	0	H ₂ S very strong
28	20-5	15	0	0	0	0	0	0	0	0	0	0	0	
Total		145												

June, 1923

1-61 meters

TABLE XXXII. *Bottom water analysis. Third Sister Lake, 1927.*

West End of Lake

Depth meters	Month: October 11					November 8					November 15				
	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.
0	15.8	7.7	5.58	2.0											
2	15.7	7.7	5.52	2.0											
4	15.5	7.6	5.50	2.1											
6	15.3	7.6	4.74	3.0		9.1	7.6	5.23	3.0	88	8.1	7.6	4.88	3.0	85
7.5	15.2	7.2	2.44	5.0											
8	14.1														
10						9.1	7.6	5.09	3.0	87	8.0	7.6	4.53	3.0	85
12						9.1	7.6	4.88	3.0	89	8.0	7.6	4.53	3.0	86
14						9.1	7.6	4.88	3.0	89	8.0	7.4	4.32	5.0	86
16											7.7	7.4	4.04	5.0	89
17.5											7.6	7.1	2.09	10.0	95
											7.4	7.0	0.07	17.0	101

Samples taken just above bottom, where water was respectively 0, 2, 4, 6, 7.5, 8, 10, 12, 14, 16, and 17.5 meters deep. All samples collected with Kemmerer sampler. Sampler lowered until it touched bottom, raised a few inches, and then closed. First water from sampler discarded in each case since it always was rather turbid.

TABLE XXXIII. *Vertical physical-chemical determinations. Third Sister Lake, 1927.*

Station 1

18 meters

Depth meters	Month: October 11					November 8					November 15				
	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.	Temp. Cent.	pH	Oxygen cc. per l.	Free CO ₂ ppm.	M.O. Alk. ppm.
0	15.8	7.7	5.58	2.0	80	9.0	7.6	5.55	3.0	82	9.2	7.6	5.44	3.0	84
1	15.7	7.7	5.6	2.0	..	9.0	7.6	5.42	3.0	..	8.8	7.6	5.40	3.0	..
2	15.6	7.6	5.58	2.0	84	9.2	7.6	5.28	3.0	86	8.7	7.6	5.38	3.0	85
3	15.5	7.6	5.16	3.0	..	9.2	7.6	5.22	3.0	..	8.5	7.6	5.02	3.0	..
4	15.5	7.4	4.60	4.5	89	9.2	7.6	5.20	3.0	86	8.2	7.6	4.75	3.0	85
5	15.3	7.3	0.0	5.0	..	9.2	7.6	5.01	3.0	..	8.15	7.6	4.70	3.0	..
6	14.4	7.0	0.0	6.0	110	9.2	7.5	4.40	3.0	90	8.1	7.5	4.65	4.0	86
7	11.2	7.0	0.0	7.0	..	9.1	7.3	0.61	5.0	..	8.05	7.5	4.40	4.0	..
8	9.1	7.0	0.0	10.0	..	8.1	7.1	0.14	10.0	..	8.0	7.5	2.23	8.0	100
9	8.2	6.8	0.0	18.0	120	7.4	7.0	0.06	15.0	105	7.9	7.0	0.06	15.0	..
10	7.9	..	..	..	..	7.4	..	..	..	..	7.5	..	..	..	..
11	7.7	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
12	7.6	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
13	7.4	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
14	7.4	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
15	7.4	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
16	7.4	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
17	7.3	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..
18	7.2	..	..	..	..	7.4	..	..	..	..	7.4	..	..	..	..

TABLE XXXIV. Physical chemical determinations. Douglas Lake.

Date	Temperature Cent.			Thermocline		pH			Oxygen cc. per l.			Free CO ₂ ppm.			M.O. Alkalinity ppm.		
	S.	u.l.H.	B.	Limits meters	Fall in Temp.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.	S.	u.l.H.	B.
1923																	
a. Aug. 18	20.7	N.S.	16.4	N.S.	N.S.	8.1	N.S.	7.3									
1926																	
b. June 25	16.7	N.S.	15.4	N.S.	N.S.	8.4	N.S.	8.2									
c. June 28	17.3	N.S.	15.3	N.S.	N.S.	8.4	N.S.	8.2									
d. Aug. 20	20.0	N.S.	19.8	N.S.	N.S.	8.4	N.S.	8.0	6.0	N.S.	5.58	0.0	N.S.	0.0	125	N.S.	128
e. Aug. 20	20.0	N.S.	19.7	N.S.	N.S.	8.4	N.S.	8.0	6.0	N.S.	5.51	0.0	N.S.	0.5	125	N.S.	127
1928																	
f. July 5	22.6	N.S.	17.2	N.S.	N.S.	8.2	N.S.	7.6	5.65	N.S.	4.40	0.0	N.S.	5.0	...	N.S.	123
g. July 5	22.6	N.S.	18.2	N.S.	N.S.	8.2	N.S.	7.8	5.58	N.S.	4.62	0.0	N.S.	3.5	...	N.S.	124
h. July 5	22.6	N.S.	17.4	N.S.	N.S.	8.2	N.S.	7.7	5.65	N.S.	5.06	0.0	N.S.	3.5	...	N.S.	122
i. July 7	23.3	18.3	17.3	5-7	4.1	8.2	8.2	8.2	6.02	5.50	5.0	0.0	0.0	0.0	...	134	126

a. Maple Point depression.
b. and c. Grapevine Channel.
d. North Fish-tail Bay, Station 70.
e. North Fish-tail Bay, Station 60.
f. North Fish-tail Bay, center of bay.
g. North Fish-tail Bay, near center of bay.
h. North Fish-tail Bay, midway between Hook and Diogenes Points.
i. North Fish-tail Bay, in cove behind Diogenes Point.

